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Sources of nitrogen and phosphorus in stormwater drainage from established residential areas and options for improved management

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Sources of Nitrogen and Phosphorus in Stormwater Drainage from Established Residential Areas and Options for Improved Management

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USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

ABSTRACT

From early April 2002 to June 2003, a study was conducted at Wanneroo and Bannister Creek in Perth's metropolitan area (Western Australia), aiming to quantify major sources of nitrogen (N) and phosphorus (P) entering urban residential catchments on two of the major dunal systems. The export of N and P from these catchments in stormwater discharge was measured, allowing investigation of some of the key pathways through which N and P enter the drainage network from the catchment. This information was then used to recommend catchment management approaches to reduce nutrient discharge into stormwater.

The study revealed that the major nitrogen sources at both sites were from fertiliser application and deposition of vehicle emissions, with a monthly total TN input load of 0.45 ± 0.05 (mean ± Standard Error) g m^{-2} at Bannister Creek and 1.75 ± 0.15 g m^{-2} at Wanneroo. The major phosphorus sources were also from fertiliser application at both sites with the monthly total TP input load of 0.07 ± 0.01 g m^{-2} at Bannister Creek and 0.13 ± 0.05 g m^{-2} at Wanneroo. The nitrogen output load discharged in the stormwater drain was 0.37 g m^{-2} yr^{-1} at Bannister Creek and 0.05 g m^{-2} yr^{-1} at Wanneroo. The phosphorus output load discharged in the stormwater drain was approximately 0.03 g m^{-2} yr^{-1} at Bannister Creek and 0.01 g m^{-2} yr^{-1} at Wanneroo. When assessing and comparing key pathways for N and P entering the catchment, it was revealed that the plant uptake accounted for approximately 40-90% removal of the incoming nutrient load. Denitrification processes accounted for approximately 7-15% of N loss, while leaching, volatilisation accounted for less than 2% and 1% respectively. Discharge from the drain accounted for less than 1% up to almost 3% of N loss. Approximately 10-60% of P input was leached into the soils, while only 1% to 3% was discharged in the drain. However, a large proportion of the nutrients stored in the catchment can ultimately end up in receiving waters. The recommended catchment management approaches to reduce nutrient discharge from stormwater drains were to take all possible sources and pathways of N and P into consideration. The holistic view of catchment management approaches, both at source control and in-transit control as well as end-of-pipe control available in the water sensitive urban design manual prepared by Department of Environment in Western Australia, were proposed.

DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

i) incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education.

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CHAPTER 1: INTRODUCTION

1.1 Background

The world's population living in urban areas has grown substantially during the past two centuries and this trend is expected to continue (UNDP, 1999). The number of dwellers in urban areas is predicted to increase from 2.9 billion in 2000 to 4.9 billion in 2030, approximately 60% of the expected world population (UNDP, 1999). This global trend is also expected in Australia. Most Australians live in urban areas, and are increasingly sensitive to the quality of urban watercourses and the bays and coasts into which these watercourses discharge (Environmental Protection Authority of Victoria, 1988). In 1995-2000 an estimated 70% of Australia's population lived in capital cities and surrounds (Australian Bureau of Statistics, 2000; Hugo, 2001).

1.1.1 Environmental Chain Problems Caused by Urbanisation

1.1.1.1 Changes in Natural Catchment

Urbanisation has caused major changes in natural catchments by increasing the amount of impervious surfaces (including buildings, rooftops, roadways, parking areas and other transportation related facilities), removal of native vegetation, and installation of drainage systems (Azous & Horner, 2001). For example, the typical percentage of impervious area in central business districts is 95-100%; in commercial areas 70-80%; in residential areas 40-60%; and in rural areas 5-10% (Horner & May, 1999; Schueler, Claytor, Caracao, & Zielinski, 1999). Impervious surfaces reduce water infiltration capacity, and therefore increase the amount of runoff in the catchment. The runoff can collect pollutants including fertiliser used in gardens and lawns, leakage from waste disposal, pet excreta and vehicle emissions and maintenance. These pollutants can be bound to soil particles and can be carried by urban stormwater runoff into a range of receiving environments via drainage networks (Lehner, Aponte Clarke, Cameron, & Frank, 1999; Maine Department of Environmental Protection, 1992). Therefore the quality of urban stormwater is an increasingly important factor determining the health and amenity of urban waterways. In realising the community's expectations for a healthy and functional environment, stormwater pollution from urban areas has become a critical issue (Stormwater Trust, 2000).

1.1.1.2 Eutrophication

Eutrophication threatens the water quality of receiving waters (such as rivers, lakes, reservoirs, wetlands and coastal waters) in urbanised areas of the world (Department of Conservation and Environment, 1980; National Research Council, 2000; Parr, Andrews, Mainstone, & Clarke, 1999). The term "eutrophication" is derived from Greek where 'eu _' means well and '_ trope' means nourishment (Wassmann & Olli, 2004). Nixon (1995) has defined eutrophication as "the process by which a body of water becomes enriched with organic material. This material is formed in the system by primary productivity and may be stimulated to excessive levels by anthropogenic introduction of high concentrations of nutrients such as phosphorus and nitrogen".

Eutrophication has become a problem because there have been enormous changes in land use and populations (Reinhardt et al., 2005; Weller, Jordan, Correll, & Liu, 2003). This has led to an increase in urbanisation, vegetation clearing, agriculture, and industrialisation which has resulted in erosion, elevated nutrient inputs and increases in the volume of water discharged from the catchment, which influence the quality and quantity of urban stormwater (Bowen & Valiela, 2001; Parikh, Taylor, Hoagland, Thurston, & Shuster, 2005; Peters & Donohue, 2001). Urban stormwater runoff from residential areas often contains high concentrations of fertiliser (Hamilton, 1992; Water and Rivers Commission, 1997). Nutrients that are not taken up by plants in lawns and gardens will be transported into wetlands via surface runoff entering stormwater drains, or will leach through the soil profile and enter the wetlands through groundwater (Balla & Davis, 1993; Water and Rivers Commission, 2001). Stormwater drainage with significant nutrient loads can promote excessive algal growth in receiving environments (Water and Rivers Commission, 2001).

Nutrient enrichment of receiving waters occurs naturally but can also be accelerated by human activities (Henderson-Sellers & Markland, 1987). The latter is commonly referred to as 'cultural' eutrophication. Eutrophication has developed from a local problem into a global issue, one of the biggest and most widespread problems of fresh waters, and an increasing problem for estuaries and coastal waters (Harper, 1992; Wassmann & Olli, 2004). Key nutrients involved in eutrophication are phosphorus in the form of phosphate and nitrogen in the form of nitrate or ammonia. In addition, inputs of bioavailable organic phosphorus and nitrogen can cause eutrophication, as bacteria can mineralise these organic forms (Aertebjerg, Andersen, & Hansen, nd; European Environment Agency, 2001).

Typically, it is phosphorus that is the limiting nutrient of eutrophication in freshwater systems (such as lakes, river streams and all inland waters) while nitrogen is limiting in coastal marine ecosystems (National Research Council, 2000). Nutrient assimilation in these blooms contributes to the enrichments when the blooms fall down and decompose. Nutrients in sediments can subsequently resurface to support nuisance algal growth (Douglas, Beckett, & Hart, 1993).

Eutrophication has accompanied human settlement from ancient times. For example, by cutting trees and building roads, the ancient Romans exposed the limestone strata, thereby increasing erosion and nutrient drainage into Lago di Monterosi. This caused an eutrophic period in the lake's history (Connel, 1993). Eutrophication was recognised as a distinct problem of water pollution by the scientific community in the 1940s and 1950s. Coupled with increasing public concern, research effort and expenditure on management techniques was increased from 1960 to 1970 (Harper, 1992).

In Australia, eutrophication has long been recognised as a serious problem with Croome, Tyler, Walker, and William (1976) concluding that many of the urbanised river systems along the east coast of Australia exhibit the characteristics of eutrophication. Investigations have been carried out on the Hawkesbury-Nepean River (Australian Environment Council, 1987), Brisbane River estuary (Moss, 1990) and the Fitzroy River estuary (Connell, Bycroft, Miller, & Lather, 1981), revealing problems with nutrient enrichment. In New

South Wales, the world's largest recorded outbreak of cyanobacteria stretched 1,000 km along the Barwon-Darling River, in late 1991 (NSW Department of Land and Water Conservation, 2000).

In Western Australia, cultural eutrophication is known to have followed European settlement. The combination of clearing and excavating land for agriculture in the catchments, together with urbanisation and industrialisation, has led to poor water quality as fertilisers from these landuses runoff into waterbodies. This runoff has been generating sediment in the Swan-Canning Rivers since the 1920s (Swan River Trust, 1999b). Many water bodies have exceeded their assimilative capacity and this has resulted in a rapid growth and accumulation of macroalgae causing beach blanketing and clogging at the middle and lower basins of the Swan-Canning estuary. The Swan and Canning Rivers have experienced an increase in the frequency and duration of algal blooms over the last 20 years (Swan River Trust, 1999b). In 1987, the Swan River Trust commenced monitoring of nutrients in 15 major tributaries to the Swan-Canning estuary (Donohue, Deeley, Parsons, & Young, 1994). In addition, samples collected between 1987 and 1992 indicated that large amounts of nutrients, particularly phosphorus (approximately 72.5 tonnes per annum) and nitrogen (approximately 750 tonnes per annum) were entering the Swan and Canning Rivers from surrounding catchments (Swan River Trust, 1999b). These catchments include large areas of residential development. It is also clear that almost all of the major wetlands within the Perth metropolitan area are under increasing threat because of the use of wetlands as compensation basins for stormwater drainage (Murdoch University, 1991, 1994) and many are classified as eutrophic and hypertrophic (Balla & Davis, 1993). Algal blooms and fish deaths in the spring and summer of 1993-94 (Swan River Trust, 1999b), led the Minister for the Environment to establish the Swan-Canning Cleanup Program (SCCP) Task Force to develop an Action Plan to reduce eutrophication. The Action Plan for the SCCP was completed in 1999 (Swan River Trust, 1999b). However, for the first time recreational contact on the Swan River was banned for 12 days from 10 to 22 February, 2000 due to the presence of cyanobacteria (*Microcystis aeruginosa*) (Jacob, 2000; Lund, 2003).

Eutrophication has been identified as the greatest threat to the health of estuarine ecosystems in the south west of Australia (GWA, 1992). Many local water bodies and drainage discharge outlets in Perth have experienced regular algal blooms. Algal blooms are of particular concern for managers of stormwater discharges as they are not aesthetically pleasing and some species have potential human health implications (Hosja & Deeley, 1994). Urban runoff is an often underestimated source of nutrients which can lead to increased phytoplankton populations in receiving waters (Hamilton, 1992). Hendersen and Jarvis (1995) found that many urban drains contain high enough concentrations of total phosphorus to cause algal blooms given optimum conditions for algal growth in the receiving water bodies. Algal blooms can affect public health, which severely limits recreational uses such as fishing and boating throughout spring and summer. The occurrence of blooms varies with time, location and magnitude depending on the current flow and climatic conditions (Swan River Trust, 1999b).

1.1.1.3 Urban Stormwater Pollution

Urban stormwater pollution has become the most important source of nutrient enrichment for wetlands in the United States of America (U.S. Environmental Protection Agency, 1997). It also became a major environmental concern in Australia during the 1980s and 1990s, partly because urban areas continued to grow, placing greater stress on urban catchments (Lawrence & Breen, 1998). In many urban areas, stormwater runoff is the major pollutant to waterways and the main factor contributing to the quality of the receiving water (Environmental Protection Authority of Victoria, 1988). Issues range from the highly political profiles of the Hawkesbury-Nepean in Sydney to rising community awareness of the effects of pollution on the Swan River in Perth (Nancarrow, Jorgensen, & Syme, 1995). In response to these issues, a research project was conducted in Brisbrane, Sydney, Melbourne and Perth with the aim to take a national approach to community catchment management of stormwater runoff in order to establish the national guidelines for stormwater management within an Integrated Catchment Management (ICM) framework (Nancarrow et al., 1995). In many parts of Western Australia, polluted urban stormwater runoff has been recognised as the most significant contributor to the deterioration of water quality in natural and artificial waterways (Welker, 1995).

1.2 Stormwater

1.2.1 Definition of Stormwater

The Agriculture and Resource Management Council of Australia and New Zealand and Australian and New Zealand Environment and Conservation Council (2000) has defined 'stormwater' as "water flowing over ground surfaces and in natural streams and drains as a direct result of rainfall over a catchment". In this study stormwater is defined as water flowing from urban areas during wet weather flows, which include the major flows during and following rain, as well as dry weather flows. In dry weather flows, drainage in the study area comes from water used on lawns and gardens, groundwater, washdown (washing of cars and driveways). and illegal discharges (Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) & Australian and New Zealand Environment and Conservation Council (ANZECC), 1996; Department of Environment, 2004).

1.2.2 Causes of Stormwater Runoff

Making land suitable for agricultural and urban development on the Swan Coastal Plain often involves removal of water from low-lying land. An extensive artificial drainage network was constructed on the Swan Coastal Plain and in other parts of the south-west of Australia. Natural creeks and rivers were altered to increase their flow capacities. This involved clearing natural vegetation, straightening waterways and replacing existing natural creeks with concrete channels and pipes (Water and Rivers Commission, 2002a).

1.2.3 Traditional Stormwater Management

Traditionally, stormwater drainage has focused mainly on avoiding flooding by providing a hydraulically efficient drainage system to rapidly collect and remove stormwater runoff from certain areas via paved channels, underground stormwater pipes and by an emphasis on engineered flood control measures such as dams, dykes and levees, and detention facilities. The increased volumes and rates of stormwater runoff caused by conventional urban stormwater management can simply transfer the hydrologic impact downstream. This has resulted in significant degradation of the natural receiving environments for this drainage (Parry, 1998; U.S. Environmental Protection Agency, 1997). In Western Australia stormwater drainage is separate from the sewerage system therefore sewerage and stormwater are collected and transported via separate drainage pipes. Wastewater entering the sewer is treated to remove pollutants by a treatment plant before being discharged to the receiving waters. Stormwater, transported in a separate system, was typically discharged untreated to receiving waters. In a major storm event, wet weather overflow from sewerage systems can contaminate stormwater. In some places the sewerage system can be combined with the stormwater system. This combined storm-sewer system collects stormwater and sewerage in a single drainage network. Wastewater entering this system is typically treated to remove pollutants by sewage treatment facilities, before being drained to receiving waters.

1.2.4 Stormwater Processes

Rainfall can be intercepted by soft surfaces such as the vegetation canopy overlying lawns and gardens, and by hard surfaces such as roofs, buildings, streets and pathways (Figure 1.1). Some of the rain falling on soft surfaces which is not used by plants will infiltrate to the soil where it can enter subsurface or groundwater flows. Plants will transpire water and evaporation from the soil will return water to the atmosphere, a combined process called evapotranspiration. When the infiltration capacity of a surface is overcome this can result in surface runoff. Hard surfaces have very low infiltration rates and so most rain landing on them will run off towards the drainage network or infiltration areas. Runoff can carry nutrients and pollutants accumulated on the catchment’s surfaces into the stormwater drainage system. Stormwater runoff from surface drainage is considered a major contributor of phosphorus to receiving waters (Hatt, Fletcher, Walsh, & Taylor, 2004). In porous sandy soils, such as on the Swan Coastal Plain of the Perth region, rainfall will rapidly infiltrate at source, therefore discharge in this catchment may be predominantly through groundwater discharge (Wong, 2004).

1.2.5 Stormwater Features

Stormwater flowing through drainage networks is seasonal, often quite flashy, and variable both in quantity and quality depending on the season and recent land use (Kadlec & Knight, 1996; Mitsch & Gosselink, 2000). This type of stormwater can have large effects on the quantity, duration, rates, frequency, and other properties of the water flow (Gosselink & Turner, 1978; Mitsch & Gosselink, 1993). These in turn can alter four major components of the environment in wetlands: hydrology, water quality, soils, and biological resources (Johnson & Dean, 1987; Leopold, 1968; U.S. Environmental Protection Agency, 1993).

1.3 Sources of N and P

Nitrogen and phosphorus inputs in aquatic systems can come from both natural processes and human activities. Natural sources of nitrogen and phosphorus include weathering processes of rock, fixation of atmospheric nitrogen by leguminous plants, decomposition of organic material, and soil leaching. Sources from human activities include fertilisers, pet waste, detergents from car washing, vehicle emissions, industrial discharge and sewage.

1.3.1 Fertiliser

Fertiliser is a major source of nitrogen and phosphorus in urban areas as it is added to lawns and domestic gardens (Kahle, 1999; Stow, Borsuk, & Stanley, 2001). For example, in one urban community within the Neuse Basin in North Carolina (USA), 90% of all homeowners used fertilisers (Osmond, nd). On average, homeowners in this community of approximately 80,000 residents applied an estimated 227 tonnes of nitrogen fertiliser to their lawns every year. This nitrogen did not include fertiliser applied to multiple dwelling residences, businesses, recreational facilities, golf courses, or schools (Osmond, nd). In Perth, it is estimated that residents collectively apply 500 tonnes of nitrogen and 200 tonnes of phosphorus to their gardens annually (Whelans, 1988) or 40 kg P ha^{-1} y^{-1} (Gerritse, Barber, & Adeney, 1990).

1.3.2 *Atmosphere*

Nutrients may be present in the atmosphere as fine particulates, liquid aerosols, or gases. Large quantities of nutrients can be added to an ecosystem from the atmosphere and these atmospheric particulates also contribute to the urban sediment load (Henderson-Sellers & Markland, 1987). Nitrogen gas (N_2) is a primary form of nitrogen in atmosphere. Atmospheric nitrogen can contain ammonia and nitrates from various sources. For example, ammonia and nitrate may be dissolved in water vapour, and other nitrogenous compounds released from the soil and plants through volatilisation and decomposition processes. Nitrates also form in small quantities as a result of lightning strikes. A variety of oxidised nitrogenous compounds are found in vehicle exhaust fumes and these contribute a considerable amount to the atmospheric nitrogen load especially near large cities (Brady & Well, 1996). Ammonia and nitrate are deposited onto land and water surfaces both as dry deposits and in rainfall as wet deposits. The combined nitrogen forms in the atmosphere are ammonia (NH_3), nitrous oxide (N_2O), nitric oxide (NO), nitrogen dioxide (NO_2) and nitrate (NO_3) (Jenkinson, 2001; Nakamura, Matsumoto, & Uematsu, 2005; Naqvi & Jayakumar, 2000). Much of the ammonia is derived from volatilisation after decomposition of plant residues (Naqvi & Jayakumar, 2000). Ammonia reacts with nitric acid (HNO_3) to form ammonium nitrate (NH_4NO_3) which can fall directly onto the catchment (Brasseur, Orlando, & Tyndall, 1999); (Cassel, Ashbaugh, Flocchini, & Meyer, 2005; Erdmann et al., 2005). Nitric acid comes from the principal NOx transformations that occur throughout the troposphere. During wet weather, lightning produces electrical energy which induces the direct combination of atmospheric oxygen and nitrogen to form nitrogen oxides (Connel, 1993; IPPC, 1994; Logan, 1983). Nitrogen oxides are also formed by the combustion of nitrogen in internal combustion engines. Once they are released into the air, they can react in air and water to form nitric acid and nitrate aerosols. When rain falls, nitric acid and nitrate aerosols may dissolve in the rainfall (Clausen & Langway, 1989; Gibaldi, 1993; Leal, Fontenele, Pedrotti, & Fornaro, 2004). Atmospheric phosphorus originates from fine particles of soil and rock, living and dead organisms, and primarily as volatile compounds released from plants, natural fires, and the burning of fossil fuels (Newman, 1995). Generally, the amount of phosphorus in precipitation is less than that of nitrogen, and in inland regions, the major source is dust from soil erosion and urban and industrial sites (Chapin & Uttormark, 1973; Cole, Caraco, & Likens, 1990; Lewis, Grant, & Hamilton, 1985).

1.3.3 Rain

Rain falling during electrical storms may contain up to 0.07 mg L^{-1} of nitrogen, and low concentrations of phosphorus (up to 0.01 mg L^{-1}), dust minerals, and sea salt may also be present (Connel, 1993). Although these low concentrations of nitrogen and phosphorus generally do not have a significant short–term ecological impact, they can be important where accumulation occurs over long periods of time (Connel, 1993). Some sources indicate that the quantity of nitrogen added to an ecosystem by electrical activity and rain ranges from 1 to 20 kg ha^{-1} annually depending on geographical location, with 5 to 8 kg ha^{-1} being typical for temperate zones (Pidwirny, 2004).

1.3.4 Pet Waste

Pet waste can increase nitrogen, phosphorus and potentially harmful micro-organisms in adjacent waters as well as increasing the Biological Oxygen Demand (BOD). As it breaks down, pet waste contributes nitrogen and phosphorus to the system. Pet waste is considered to be a minor source of nitrogen and phosphorus to stormwater in the Neuse Basin in North Carolina (USA) (Osmond, nd). The USEPA estimates that urban runoff contributes 12% to the non point - source pollution load in the USA (USEPA, 1995). N non point – sources come from animal and plant waste, septic systems, atmospheric deposition, and N fertiliser use in the landscape(primarily turf) is expected to have the largest contribution of N loads into urban receiving waters (Osmond & Hardy, 2004). In Australia, little is known about the contribution of nutrients from pet waste to stormwater.

1.3.5 Domestic Sewage and Industrial Sources

Nutrients may also be derived from domestic sewage and industrial sources. Domestic sewage may release nutrients in effluent from sewage treatment works. Nutrients from industrial sources may be locally important, depending upon on the type of industries, the volume of effluent and the amount of treatment it receives (Huang, Huang, & Yue 2003; Mason, 1981). For instance, the brewing industry produced an effluent containing some 156 mg L^{-1} N and 20 mg L^{-1} P into rivers in England and Wales in 1975 (Department of the Environment, 1978). Food processing requiring substantial washing procedures is likely to produce effluents containing high concentrations of nitrogen and phosphorus. Meatworks effluents contain 200-400 mg L^{-1} TKN and 20-50 mg L^{-1} P (Raper & Green, 2001). Effluent concentrations from the raw mixed pharmaceutical industry and domestic wastewater from sequencing batch reactors (SBR) contained some 1 mg L^{-1} $NH_3 – N$ and 8.1 mg L^{-1} PO_4^{3-} (Ileri, Sengil, Kulac, & Damar, 2003).

1.3.6 Laundry Detergent

In the USA it has been estimated that 0.3 kg P capita^{-1} y^{-1} (Booman & Sedlak, 1986) of laundry detergent and 0.1 kg P capita^{-1} y^{-1} (Sedlak, 1991) of other household detergents and cleaners are contributed to aquatic systems. The contribution from households in Australia is unknown. However in Perth most detergents are discharged from households via the sewage systems. Only detergents used in car washing are likely to enter the storm drainage network.

1.3.7 Garden Waste

Leaf litter, seeds, flowers and grass clippings from household gardens and lawns at each household can contribute to nutrient loads in the stormwater, as they may be carried away by surface runoff (Cowen & Lee, 1973; Kluesener & Lee, 1974). The total phosphorus content of leaves is typically about 0.2% of dry weight and total nitrogen is about 1% of dry weight (Cowen & Lee, 1973; Dorney, 1986; Prasad, Henry, & Kovacko, 1980), and higher nutrient contents have been found for bluegrass (Timmons, Holt, & Latterell, 1970).

1.3.8 Human Activities

Disturbance of soil in lawns, gardens, and around construction sites can result in soil erosion which can enter the stormwater drainage network directly or via wind drift. The quantities of nutrients can lose from the soil through runoff or wind drift in particularly from agricultural land (Schroder, Scholefield, Cabral, & Hofman, 2004). Much of the nitrogen and phosphorus is in the organic matter, finer particles of which are included in the eroded sediments (Brady & Well, 1996). Generally, sediments and total suspended solids can adsorb a wide range of contaminants such as nutrients, heavy metals, and toxic organic compounds in the water column (Hart, 1983; Stow et al., 2001).

1.4 Catchment Nutrient Processes and Pathways

A proportion of nutrients entering a catchment are finally exported and nutrients may be transformed into alternative forms during the process (Figure 1.1).

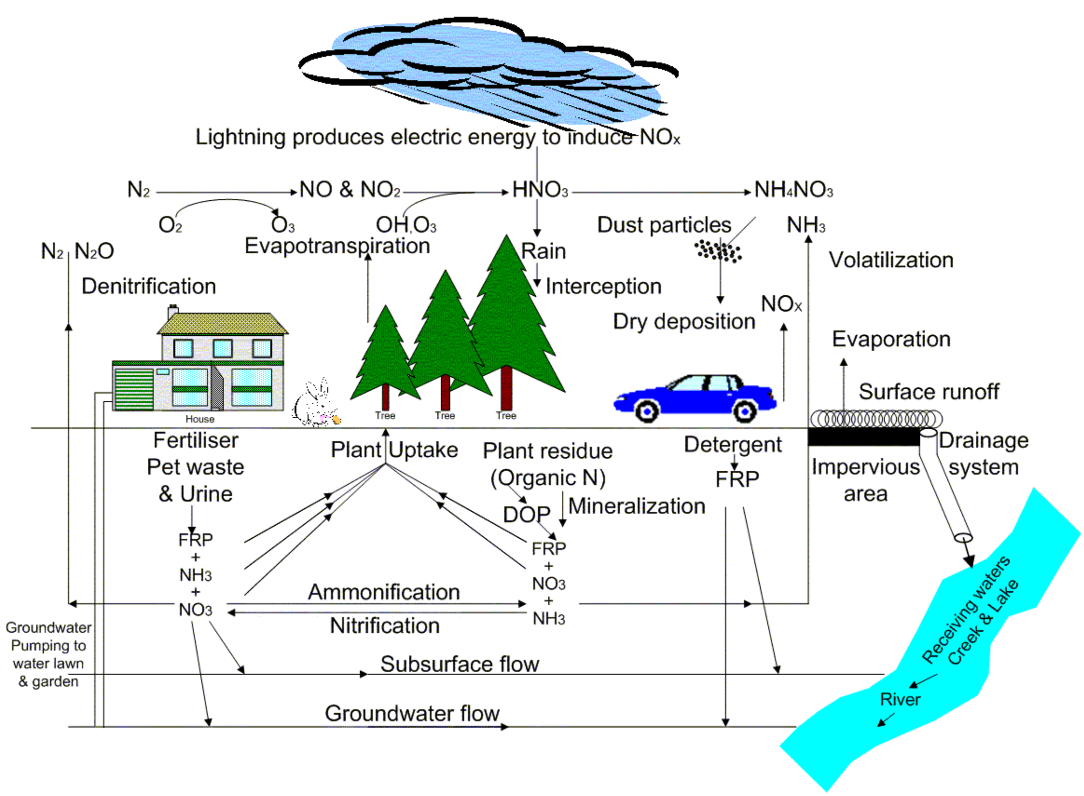


Figure 1.1 Conceptual model of residential catchment nutrient biogeochemical cycling (Based on concepts in Brady & Well 1996; Wetzel, 2001; Wong, 2004; Mitsch, & Gosselink 2000).

Fertilisers and pet waste (including urine) in the catchment contribute ammonia, nitrate, and filterable reactive phosphorus (FRP) (Brady & Well, 1996) to stormwater. Ammonium, nitrate, and FRP are readily taken up by plants and micro-organisms within the soils and assimilated. When leaves and garden litter become incorporated into soils, they are decomposed by fungi and bacteria via mineralisation processes to produce ammonia, organic phosphorus or soluble inorganic P (Brady & Well, 1996; Wetzel, 2001). Organic phosphorus exists in two forms. One is soluble, dissolved organic phosphorus (DOP), such as sugar phosphates, phospholipids, phosphoproteins and inositol phosphate. Generally, DOP is not biologically available until further mineralised into soluble inorganic forms. The other form is insoluble organic phosphorus which is usually bound in organic matter (Reddy, Kadlec, Flaig, & Gale, 1999; Van Eck, 1982). Ammonia may be oxidised by nitrifying bacteria to form nitrate, and urea in pet waste may be transformed to ammonia through ammonification processes or released as nitrate (Brady & Well, 1996; Wetzel, 2001).

Ammonia can enter the atmosphere by volatilisation (Brady & Well, 1996; Henderson-Sellers & Markland, 1987). In turn, volatilised ammonia can be deposited and precipitated to the terrestrial ecosystem by dry and wet deposition respectively (Brasseur et al., 1999).

Nutrients not used by plants or bound to soil or organic particles can dissolve in runoff or be leached into subsurface or groundwater flow. Generally, nitrate ions are readily leached from soils into subsurface water and groundwater (Bakhsh, Kanwar, & Karlen, 2005). Ammonia may also be washed into water systems in surface runoff but in typically small amounts (Brady & Well, 1996). In most soils, phosphorus is immobilised by combining chemically with iron, magnesium, calcium, and aluminium minerals to form less soluble compounds, or by being adsorbed onto the surfaces of clay and silt particles and organic matter in soil (Brady & Well, 1996; Swan River Trust, 1999b). Phosphorus leaching into groundwater or subsurface flow is limited (Saarijarvi, Virkajarvi, Heinonen-Tansk, & Taipalinen, 2004). However, the leaching into groundwater and subsurface flow can occur if phosphorus fertilisers are applied to sandy soils with low clay and mineral contents such as the sandy soils of the Swan Coastal Plain. In this case phosphorus may be transported as a suspension or rolling over the surface depending on the particle size, and a high percentage may be leached into the groundwater and subsurface flow (Schofield et al., 1985).

Detergents typically include phosphate builders (sodium pyrophosphate and polyphosphates) as a major constituent to enhance their cleaning action (Osorio & de Oliveira, 2001). Phosphorus in soluble forms such as orthophosphates, or FRP, or polyphosphates can infiltrate to subsurface flow or groundwater flow via macro-pores, or cracks within coarse textured sandy soils with low contents of iron (Fe) or calcium (Ca) (Cox, Kirkby, Chittleborough, Smythe, & Fleming, 2000; Heathwaite & Dils, 2000)

Groundwater used for watering lawns, gardens and pot plants is also a source of nutrients entering residential catchments. Nutrients are natural components of groundwater, but can be increased by household activities such as fertiliser application to lawns and gardens, car washing and pet waste disposal in gardens (Jarvie, Neal, Withers, Wescott, & Acornley, 2005; Liu & Liptak, 2000). The phosphorus content of groundwater is generally low as a result of the relatively insoluble nature of phosphate-containing minerals, the scavenging of surface phosphate by biota and its adsorption onto soil particles (Wetzel, 2001). Tap water is used on gardens but it is treated to meet the drinking water standards and therefore has low concentrations of nitrogen and phosphorus.

Sediments discharged from urban residential catchments are mainly from dust particles accumulated on the catchment's surface area as dry deposition and from soil erosion (Brasseur et al., 1999; Jaenicke, 1988; Rosewell, 1997).

During runoff, the water may entrain nutrients from the surface by dissolving them or eroding and suspending them (Henderson-Sellers & Markland, 1987). Those particles which are too large to be suspended in the water may be transported by rolling over the surface. The amount of particulates removed from a surface by runoff depends largely on its vegetative cover (Henderson-Sellers & Markland, 1987). Firstly, the structure of plants above the ground presents a physical barrier to surface runoff, thus reducing its velocity and carrying capacity (Henderson-Sellers & Markland, 1987). Secondly, root structures in the soils bind the soil particles together to further resist erosion and improve filtration via root patways.

The model proposed in Figure 1.1 can be refined to a series of sources, transport pathways and outputs that are likely in small residential suburbs in Perth. This refined model is shown in Figure 1.2 and has the following key features:

- Inputs into the catchments come from atmospheric fallouts (dry and wet deposition), household activities [garden watering (groundwater or scheme water), fertiliser applications, car washing, vehicle emissions and pet waste] and soil erosion. The two dunal systems (i.e. Bassendean Dunes and Spearwood Dunes) underlying the study sites are generally low in major nutrients and trace elements (Seddon, 1972). Householders often apply large quantities of fertiliser to overcome the infertility which, compounded with the shallow aquifer, increase the likelihood of both surface and groundwater pollution (Davies, 1992).
- During rainfall, some of the rain falls on pervious (soft) areas (garden and lawn) and can infiltrate into subsurface flow and/or groundwater, or can re-enter the atmosphere by evapotranspiration. Other rainfall will land on impervious areas potentially resulting in runoff. Runoff carries nutrients and pollutants accumulated on the catchment's surface down to the stormwater drainage system. In Perth, stormwater from individual properties is required to remain on the property and cannot be discharged to the drainage or sewerage network. Most roof gutters therefore discharge to local soakwells and then into the groundwater (Cargeeg, Boughton, Townley, & Smith, 1987; Department of Environment, 2004). Schueler (1987) found that as much as 70% of the impervious surface in residential areas is associated with transport-related functions such as roads, driveways and footpaths. This impervious area is likely to be the prominent source of nutrient and sediment contamination of stormwater in Perth residential catchments. In highly urbanised areas, particularly commercial and industrial areas with large areas of roofing and paving, up to 90% of the rainfall may flow into the drainage system as stormwater (Agriculture and Resource Management Council of Australia and New Zealand &

Australian and New Zealand Environment and Conservation Council, 2000). Therefore in this study, it was assumed that all contaminant inputs into the catchment accumulated on the surface of the catchment area.

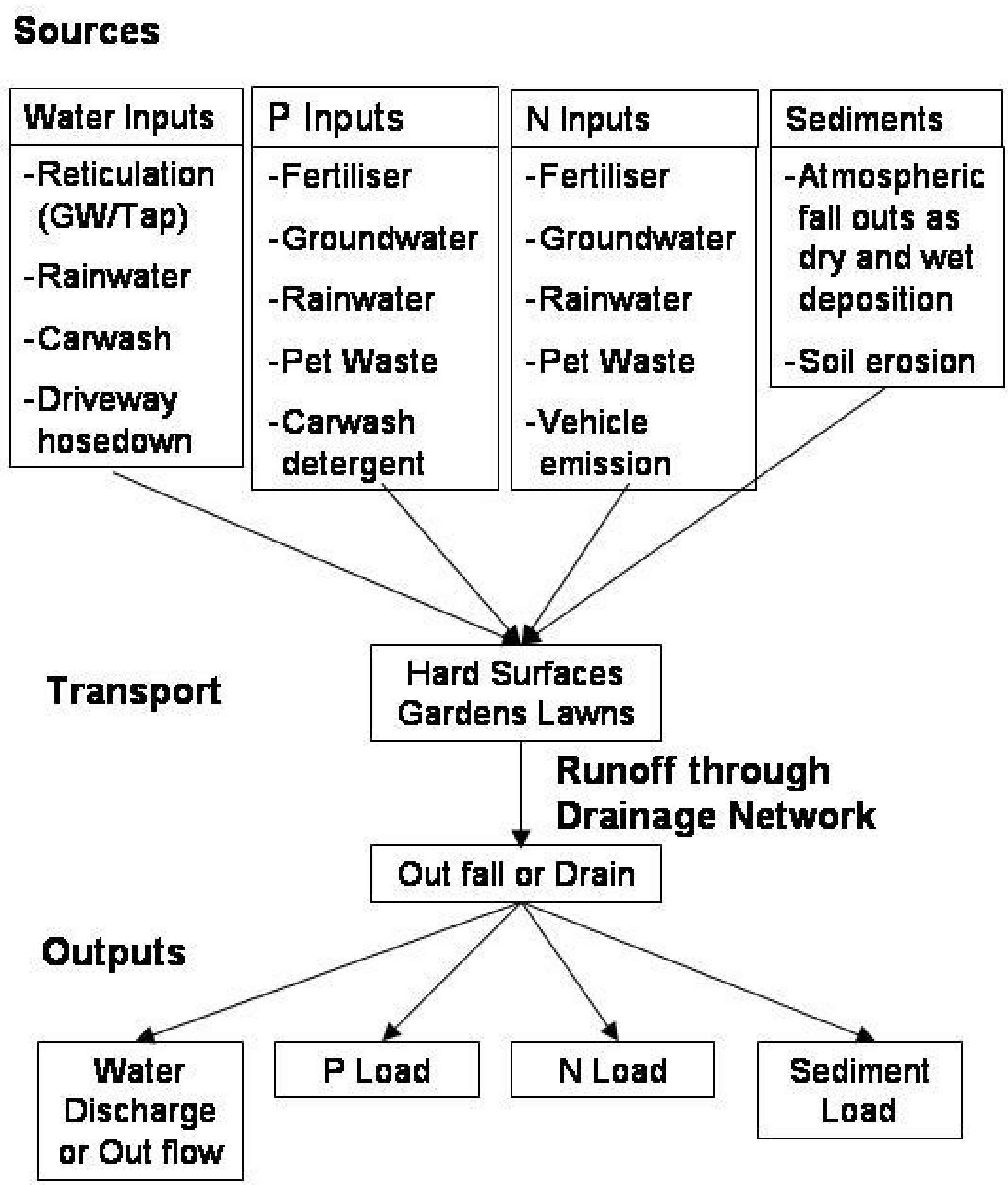


Figure 1.2 A conceptual model showing sources, transport mechanisms and outputs of nitrogen and phosphorous in established residential catchments in Perth.

- Groundwater is the most important source of water in Western Australia (Water and Rivers Commission, 1998d) for all kinds of activities, e.g. public water supply; agricultural, industrial, commercial and domestic use (watering gardens and lawns) (Water and Rivers Commission, 2000). In Perth, about 30% of households have a garden bore, and approximately 80 million kL of groundwater is pumped out from the 120,000 garden bores each year (Water and Rivers Commission, 1998b). Garden bores located in areas of polluted groundwater will pump polluted water (Water and Rivers Commission, 1998a). Excessive watering in Perth can leach out the fertiliser added to the lawns and gardens and risks contaminating the groundwater with nutrients. This is because most of Perth's soils are infertile and do not readily bind nutrients (Water and Rivers Commission, 1998a). Appleyard (1992) investigated the contribution of nutrients from groundwater to the Swan estuary (Perth) and identified that significant nitrogen inputs from groundwater entered the Swan estuary, while phosphorus inputs were relatively low.
- The stormwater drainage system in Perth is separate from the sewage system, so it was assumed that there was minimal sewage contamination. Both of the study sites are also located in areas with a sewerage system, therefore in this study it was assumed that no nutrients leaked from septic systems into the drains studied. It is possible that old septic tanks in the catchment may still contribute to nutrient pollution however most of the contamination will be directed towards the groundwater.

1.5 Nutrients in Stormwater Discharge

1.5.1 Factors Affecting Nutrient Concentration

Nutrient concentrations in stormwater can be extremely variable over time. There are a large number of factors that can influence the quantity of stormwater and nutrient concentrations and these directly affect the nutrient load being discharged from the catchment. These factors are land use (type and the proportion of impervious areas), climatic influences (rainfall intensity, duration and time between rainfall events, the first flush of initial stormwater runoff), soil types, topography and the design and management of stormwater systems (Hale, 1995; Newman, 1995).

1.5.2 First Flush Phenomena Versus Nutrient Concentrations

As a result of the Mediterranean climate (typified by winter and spring precipitation and summer drought) in Perth, a long period for pollutant build-up naturally occurs. Nutrient concentrations and loads are generally greatest, both spatially and temporally, in the early stages of winter runoff. This is caused by stormwater runoff flushing accumulated nutrients from the catchment surface. The first flush effect is predominantly noticeable after prolonged dry weather periods around February or March and typically contains the highest pollutant concentrations for that season due to the relatively long accumulation time (Urbonas & Stahre, 1993). In Perth, the first flush effect is often compounded by soils with non-wetting properties, which may behave like an impermeable surface during the first flush. Quantification of the first flush effect needs to be carried out by an intense sampling program to assess spatial and temporal heterogeneity (Ellis, 1989). Therefore many studies have identified the first flush phenomenon as the initial period of stormwater runoff in the winter season which is called a seasonal first flush and usually has substantially higher pollutant concentrations compared with later stages of rain storms (Gupta & Saul, 1996; Kim, Kayhanian, Lau, & Stenstrom, 2005; Lee, Bang, Ketchum, Choe, & Yu, 2002).

In a storm event, a first flush phenomenon occurs when most of the pollution load is transported in the initial part of the event discharged volume (Taebi & Droste, 2004). It is assumed that there is a significant first flush if at least 80% of the total pollutant mass is transported in the first 30% of the volume discharged during the rainfall event (Bertrand-Krajewski, Chebbo, & Saget, 1998). The magnitude of the first flush phenomenon, and if it actually occurs, was calculated using a method of data analysis which results in determining the “event mean concentration (EMC)” (Lee et al., 2002).

In systems without storage, this first flush of pollutants may be discharged from the system and result in the heavy pollution of the receiving watercourse (Gupta & Saul, 1996). Results from first flushes suggest that applying Best Management Practices (BMPs) early in the season could remove several times more pollutant mass than randomly timed or uniformly applied BMPs (Lee, Lau, Kayhanian, & Stenstrom, 2004).

1.5.3 First Flush Criticism

At present, the first flush phenomenon of storm event is a controversial issue among scientists mainly resulting from the unclear definition of the phenomenon (Saget, Chebbo, & Bertrand Krajewski, 1996). The data originate from a French database based on the quality of storm event from 80 events of 7 separately sewered basins, and 117 events of 7 combined sewered basins. This study revealed that the first flush phenomenon is very scarce (Saget et al., 1996).

Many research studies have both supported and argued against the first flush concept in the same study. For instance rain/discharge measurements in Denmark included 160 storm events corresponding to an accumulated rain depth of 753 mm from a 2 year period on a 95 hectare urban catchment. The water quality measurements included 15 events with time series of concentration of SS, COD, BOD, total nitrogen and total phosphorus. The quality parameters showed significant first flush effects. The paper discusses whether the event average concentration or the accumulated event mass is the most appropriate way to characterise the quality of the outflow (Larsen, Broch, & Andersen, 1998). In South Korea stormwater runoff was monitored on 13 separate urban watersheds, which were chosen to represent distinct types of residential and industrial development, along with various watershed characteristics. A total of 38 storm events were monitored to investigate the first flush phenomenon. The magnitude of the first flush phenomenon was found to be greater for some pollutants (e.g. suspended solids from residential areas) and less for others (e.g. chemical oxygen demand from industrial areas). No correlation was observed between the first flush phenomenon and the antecedent dry weather period, however, the first flush phenomenon was greater for smaller watershed areas (Lee et al., 2002).

In an attempt to distil multiple definitions of the first flush phenomenon into a consistent framework and examine common volumetric capture requirements, eight rainfall-runoff events in Louisiana (USA) were examined from each of two small paved urban transportation land use watersheds with areas of 544 m^2 and 300 m^2 respectively (Sansalone & Cristina, 2004). Results indicated that two separate criteria must be employed to describe the delivery of pollutants (mainly suspended sediment concentration SSC, and total dissolved solids TDS) as aggregate indices of entrained particulate and dissolved matter. Firstly, the concentration-based first flush criterion is defined by high initial pollutant concentration in the early portion of a rainfall-runoff event with a subsequent rapid concentration decline. Secondly, in contrast, the mass-based first flush (MBFF) equivalent is defined generally as a disproportionately high mass delivery in relation to corresponding flow volume. For mass-limited events, mass delivery was skewed towards the initial portion of the event while the mass delivery in flow limited events tended to follow the hydrograph.

Nutrients in stormwater, expressed as either concentration or mass load discharged from a catchment, are considered to be dramatically variable. This is because of the complexity of the phenomena involved and the multiplicity of influencing factors mentioned above. When combining those factors with historical fertiliser applications, possible water table interactions with septic tanks and subsurface drainage systems, the concentrations and loads of nutrients are extremely variable (Hale, 1995).

1.6 Urban Stormwater Management in Western Australia

1.6.1 Aims

The Department of Environment (formerly the Water and Rivers Commission, Western Australia) has been attempting to reduce eutrophication problems by encouraging new developments to adopt Water Sensitive Urban Design principles (Department of Environment and Heritage, 2002; Water and Rivers Commission, 1998c) which aim to protect natural systems, integrate stormwater treatment into the landscape, protect water quality, reduce runoff and peak flows, and add value while minimising development costs (Victorian Stormwater Committee, 1999).

1.6.2 Water Sensitive Urban Design

Water Sensitive Urban Design (WSUD) is the integration of water cycle management which covers a large aspect of drinking water, stormwater runoff, waterway health, and sewage treatment into urban planning and design (Whelans & Halpern Glick Maunsell, 1994). WSUD measures are simple treatment measures that collect, reuse and treat rainfall that falls onto urban area by improving the quality of stormwater before it reaches the local waterway.

Retrofitting is the process of installing or undertaking additional or alternative stormwater management devices or approaches in an existing developed area. It includes increasing temporary storage of stormwater, on-site reuse of water and increasing infiltration, for example by reducing the area of impervious surfaces. Retrofitting can occur at the lot, block/neighbourhood or catchment scale. Redeveloping or upgrading existing developments and infrastructure particularly presents opportunities for retrofitting (Department of Environment, 2004).

A superficial aquifer and drainage channels located in Western Australia generally include both stormwater from surface runoff and groundwater that are purposely intercepted by installed drains to control seasonal peak groundwater levels. Stormwater management in Western Australia is unique because stormwater and groundwater probably need to be managed simultaneously.

Rainwater potentially recharge the superficial aquifer either prior to start of runoff or throughout the entire travelling time of runoff in the catchment. Urban stormwater on the Swan Coastal Plain is an important source of recharge to shallow groundwater, which supports consumptive use and groundwater dependent ecosystems.

1.6.3 A New Comprehensive Approach

A new comprehensive approach of stormwater management in WA is based on the principle that stormwater is a valuable resource– with social, environmental and economic opportunities. The community currently has environmental awareness increasing and recently has experience with water restrictions. This will be a major cause in influencing a change from stormwater being seen as a waste product with a cost, to a resource with a value.

Urban development, water sensitive urban design and drain retrofitting in the catchment scale can play an important role to Water Corporation, Swan River Trust, and local Government Authorities in WA to closely cooperation in dealing with water cycle management which is an important consideration for urban development that contributes to an ecologically sustainable city.

However in established residential areas that have existing stormwater drainage infrastructures, these principles are very expensive and difficult to apply. Therefore, alternative approaches, both drain retrofitting (Swan River Trust, 2000) and Best Management Practices (Water and Rivers Commission, 1997), are adopted to reduce the nutrient outputs from established residential areas. The Swan–Canning Cleanup Program (SCCP) and the Water Corporation started to plan extensive modifications to the drain infrastructure in 2000 with the hope that drain retrofitting can improve water quality in the Swan River by reducing nutrient inputs (Swan River Trust, 2000). Currently in Perth, little is known about the nutrient sources within catchments and the significance of stormwater discharges from residential areas, making it difficult to determine the most cost-effective way to reduce nutrient loads.

1.7 Aims

This project aims to look at and understand the differences in results of nutrient loads between the two catchments by discharge calculation through the Manning equation and multiplying with nutrient concentrations, investigate attitudes and practices of all kinds of human's activities concerning N and P applications through questionnaires, and compare and contrast the two small established residential catchment sites in order to improve management of stormwater drainage in two small established residential catchments.

Specifically, the research will:

Quantify major sources of nitrogen (N) and phosphorus (P) entering urban residential catchments on two of Perth's major dunal systems.

Quantify N and P stormwater discharge from these urban residential catchments, and assess and compare key pathways through which N and P enter the drainage network from the catchment sources.

Recommend catchment management approaches to reduce nutrient discharge from stormwater in these catchment types.

CHAPTER 2: STUDY SITES

2.1 Perth

Two sites in the Perth metropolitan area were examined in the study, at Bannister Creek and Wanneroo (see Figure 2.1). The area of the study site in Bannister Creek was 999,950 m^2 and in Wanneroo was 197,376 m^2. Bannister Creek and Wanneroo in this study has been defined as follows. Wanneroo site in this study is defined as an area which surrounds with Ariti Av, Frederick St, Yallambee Cr, and Pinnelli Rd. Bannister Creek site in this study is defined as an area which surrounds with High Rd, Metcalfe Rd, Lyndale Av and Vellgrove Av.

2.1.1 Location

The city of Perth is located in the south-western corner of Australia (31° 57’ S and 115° 51’ E). Perth lies on the Swan Coastal Plain (SCP). The SCP was defined by Seddon (1972) as being “the coastal plain along the west coast of southwest Australia, extending from Geraldton in the north, to Dunsborough in the south”. It covers an expanse of 550 km of coastline, and at its maximum, extends eastward for 35 km to the Darling Scarp (Balla, 1994)

2.1.2 Landform

The SCP consists of four major landforms that run parallel to the coastline (Figure 2.2). The most easterly landform is the Pinjarra Plain, which is an alluvial plain located at the foot of the Darling Scarp (Seddon, 1972). The three successive landforms, the Bassendean, Spearwood and Quindalup dunes, consist of a series of dune systems that formed during periods of higher sea levels. The Darling and Gingin scarps represent the boundary of marine intrusion which occurred during the Tertiary and Quaternary periods (McArthur & Bartle, 1980). Wetlands on the Swan Coastal Plain mostly lie in the interdunal swales of the dune system, in the interbarrier depressions between the Spearwood Dune and Bassendean Dune systems (Arnold, 1990).

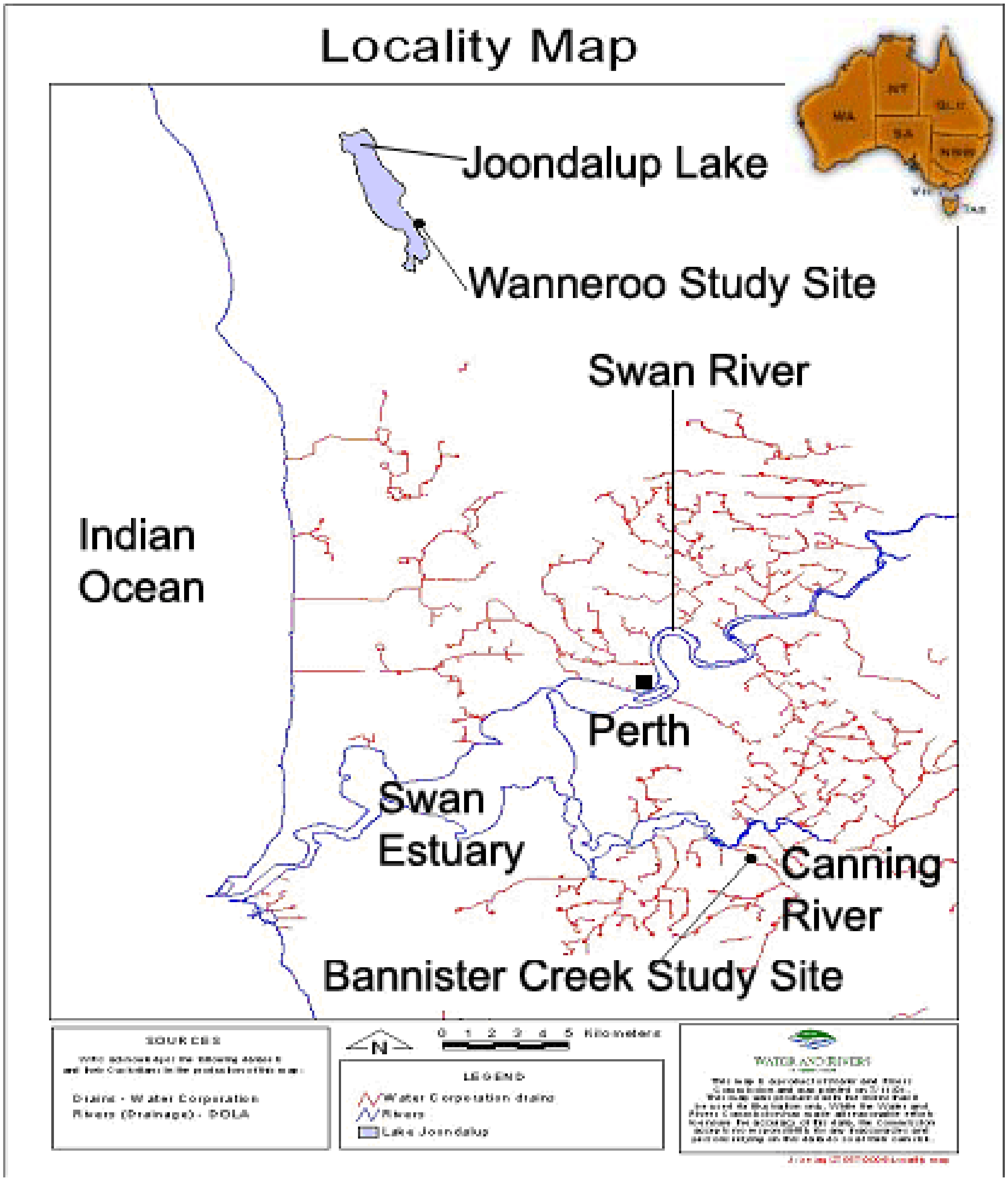


Figure 2.1 Location of the study sites at Wanneroo and Bannister Creek (Supplied by Department of Environment WA).

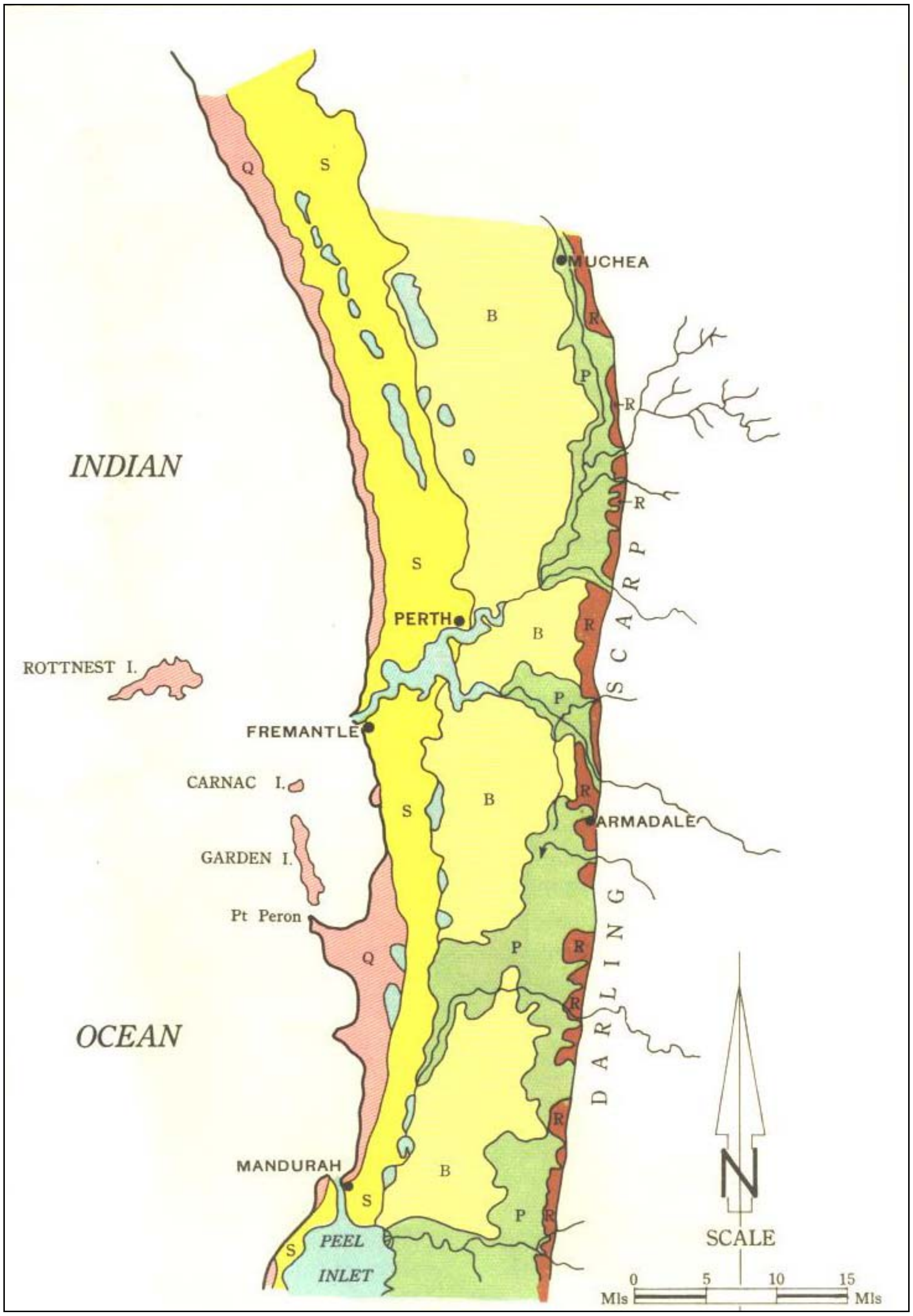


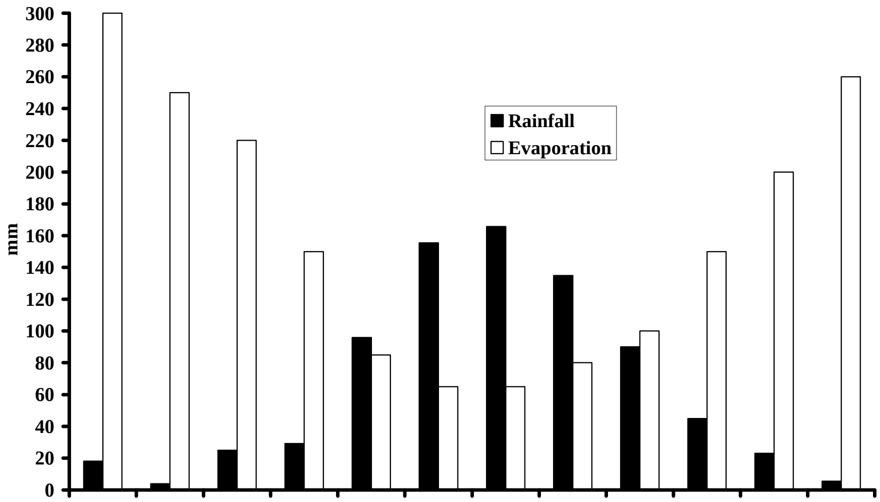
Figure 2.2 Geology and soils of the Swan Coastal Plain. Ridge Hill shelf (R), Pinjarra Plain (P), Bassendean Dunes (B), Spearwood Dunes (S), Quindalup Dunes (Q), (W. M. McArthur & Bettenay, 1974).

2.1.3 Climate

Perth has a Mediterranean type climate with a hot, dry summer and a cool, wet winter (Vollprecht, 1969). The hot, dry summer is a result of a series of anti-cyclones (high-pressure zones) that pass over the region during summer (Davidson, 1995). The cool, wet winter is associated with the sub-polar, low pressure cells that cross the south-west of Western Australia as cold fronts travelling from west to east. This results in a highly seasonal rainfall pattern, with most (~90%) of the rain falling between April and October (Figure 2.3). Mean monthly rainfall is greatest during the months of May, June, July, August and September (Figure 2.3) and the long-term annual average rainfall recorded in Perth is 775 mm (BOM, 2005a, 2005b) .

The monthly average evaporation for Perth is 161 mm with the highest monthly evaporation of 300 mm occurring in January (Figure 2.3) and the lowest monthly evaporation of 65 mm in June and July. Class A pan evaporation is 1925 mm per annum. Precipitation usually only exceeds evaporation between May and August (BOM, 2005a)

Annual variations in temperature range from a mean daily maximum temperature of 31.2 °C in February and a mean daily minimum temperature of 8.1 °C in July (Figure 2.3) (BOM, 2005b) to a mean maximum of 24.5 °C (Figure 2.3) and a mean minimum of 12.8 °C (BOM, 2005b; Seddon, 1972). Under the influence of blocked summer highs, temperatures can, and often do, exceed 38 °C; on average this occurs for five days of the year (Gentilli, 1975).



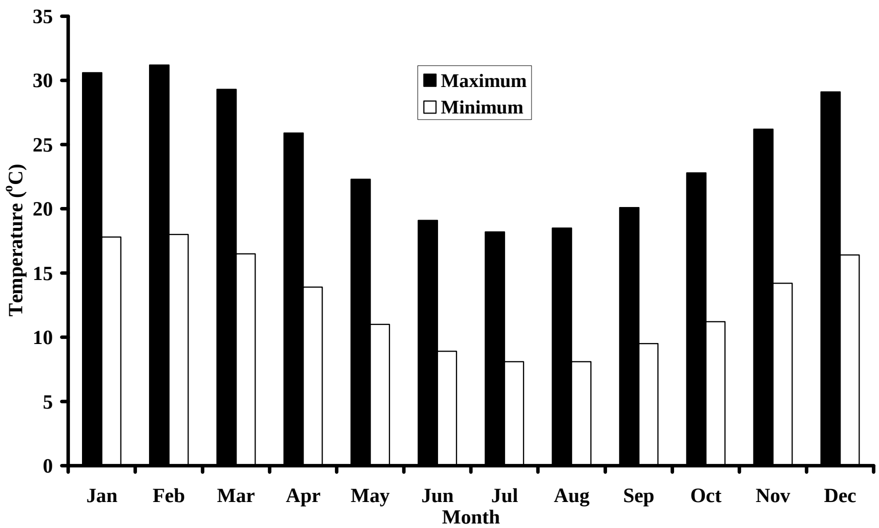


Figure 2.3 Average rainfall and evaporation (top), and maximum and minimum of temperatures (bottom) based on at least 10 years of records from Bureau of Meteorology..

2.1.4 Groundwater

The Perth Region contains a very large and renewable groundwater resource (Davidson, 1995). The Gnangara and Jandakot Groundwater Mounds are two shallow, unconfined groundwater mounds occurring to the north and south of the Perth metropolitan area respectively (Figure 2.4). The superficial aquifer averages about 50 m in thickness. Below the superficial aquifer there are a number of confined aquifers, the largest and most extensive of which are the Leederville, which is typically several hundred metres thick, and the Yarragadee, which is often greater than 1000 metres thick (Water and Rivers Commission, 2004).

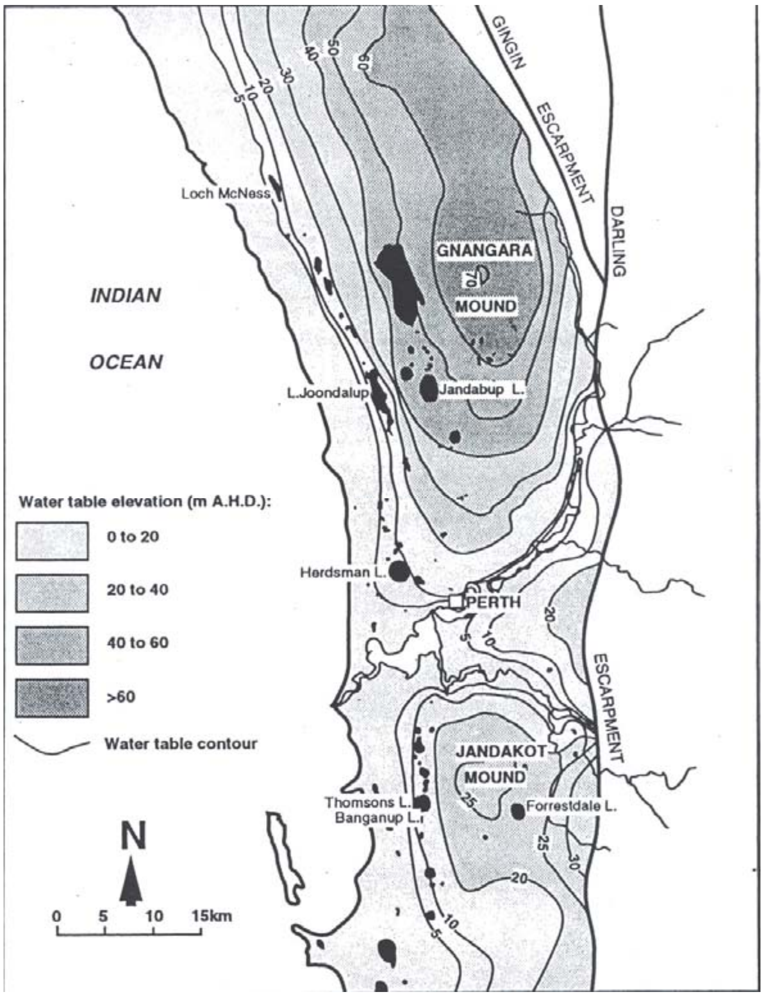


Figure 2.4 Location of the Gnangara and Jandakot Groundwater Mounds (Froend, Farrell, Wilkins, Wilson, & McComb, 1993).

The wetlands occurring on the groundwater mounds are surface expressions of the underlying unconfined aquifer and their water levels tend to vary with that of the watertable (Water Authority of WA, 1991). The lakes are also recharged directly by rainfall infiltration, surface runoff, and artificial drainage waters. Discharge from the lakes is composed of evapotranspiration, occasional drainage and groundwater outflow (Water Authority of WA, 1991). The lakes reach their maximum depths at the end of winter in response to the winter rains and drop to minimum levels (often becoming dry) at the end of summer. Over 80% of wetlands on the SCP are seasonal sumplands (*sensu* (Semeniuk, 1987) or damplands), and only contain water during these winter months (Davidson, 1995).

Perth's groundwater resources are used extensively with more than 80,000 shallow bores pumping as much as 220 million kL of groundwater per year (Water and Rivers Commission, 2004). Most of these bores provide water for maintaining domestic gardens, irrigating parks, recreational ovals and golf courses. Other bores provide water for larger irrigation projects such as market gardens, industrial purposes and drinking water supplies for Perth. Treated groundwater supplies around 127 million kL or 40% (this includes the deeper confined aquifers) of Perth's drinking water. With Perth's continued growth this is expected to expand to 50% over the next 15 years (Water and Rivers Commission, 2004).

2.1.5 Drainage System

In Australia, drainage and sewerage systems are separate (Pilgrim, 1991). Drainage systems can be divided into four parts. They are roof and property drainage, street drainage (including both pipe and surface flow), trunk drainage (consists of large conduits, usually open channel, for drainage purposes), and receiving waters (rivers, lakes, groundwater and the oceans) (Pilgrim, 1991). The water flowing in a drainage system is the runoff from the surrounding land, called the catchment. Catchments and drainage systems in the Perth metropolitan area range from 0.1 to 10 km^2 in size (Water Corporation, 2003). (The catchment areas in this study are approximately 0.2 km^2 at the Wanneroo site and 1 km^2 at the Bannister Creek site).

Drains in the Perth Metropolitan Area are owned by the Water Corporation (around 830 km) and the local shire or council (3,000 km). The drains owned by the Water Corporation are called Main drains or Branch drains. Some local council drains feed into Water Corporation drains, others discharge directly to the receiving waterway (Water Corporation, 2003).

In Western Australia most drains are piped, however larger drains can be open. Although natural drainage lines are relatively uncommon in Perth due to the sandy soils, in some instances such as Bannister Creek they have been used as drains. Perth also uses a number of compensation basins to maximise groundwater recharge and evaporation. Wetlands and rivers are the main receiving bodies for stormwater.

2.2 Bannister Creek Site

2.2.1 Location

The Bannister Creek site is located approximately 10 km south of Perth city (32^{o} 01’ 07” S and 115^{o} 55’ 59” E) with an altitude of approximately 4.65 m A.H.D. (City of Canning, 2004). The study site is located in the City of Canning’s Parkwood residential area and drains into Bannister Creek (see Figure 2.5). The study site is situated on Bassendean sand plains with low dunes overlying iron and humus podzols, peats and clays (Fisher, 1999).

2.2.2 Landform

The Bassendean Dunes, which may be up to 80 m deep, cover large areas of the coastal plain and are composed entirely of silicious sand (McArthur & Bartle, 1980). The Bassendean dunes form a gently undulating aeolian sand plain about 20 km wide. The original carbonate material has been completely leached from these soils leaving grey quartz sands with generally less than 3.5% organic matter. Hence the soil is light in colour and sandy and is usually low in clay and humus (Gozzard, 1983; Jordan, 1986). The Bassendean sands may be weakly iron-oxidised (limonite) and cemented at 2 to 3.5 metres in depth near the watertable. Therefore they are very low in iron, calcium and most other minerals, and this makes them infertile both chemically and physically (Seddon, 1972). The generally poor nutrient and water retention capabilities of these soils are important contributing factors to the contamination of the shallow aquifers and surface drainage waters on the Swan Coastal Plain. The sands have a Phosphorus Retention Index (PRI) of 0 (Gerritse & Schofield, 1989; McPharlin, Delroy, Jeffrey, Dellar, & Eales, 1990; Ritchie & Weaver, 1993).

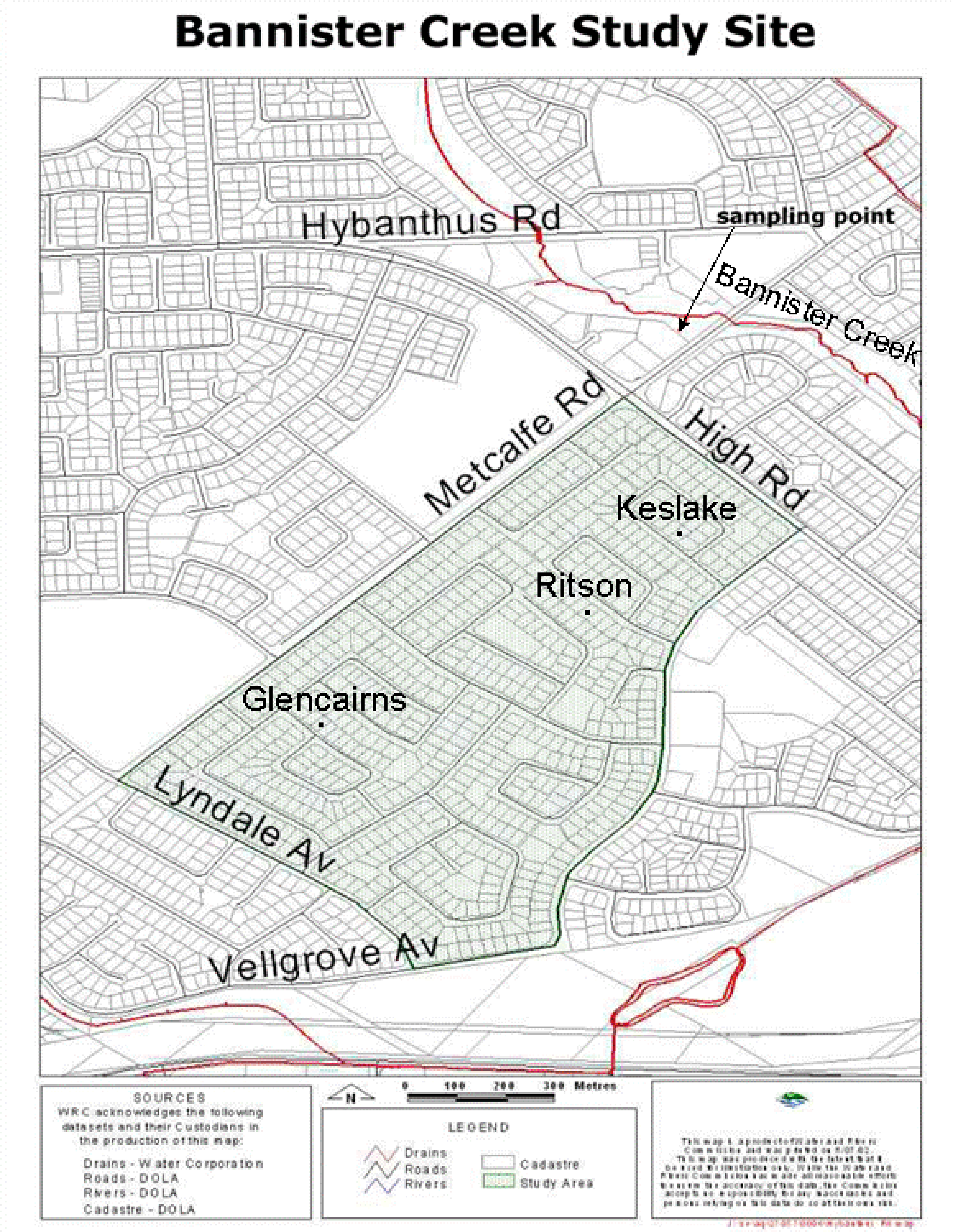


Figure 2.5 Bannister Creek site (Supplied by the Department of Environment WA).

Figure 2.6 Sampling point at Bannister Creek

2.2.3 Groundwater

The study site is located on the Jandakot Groundwater Mound. The Jandakot Mound is the smaller of the two main, shallow unconfined groundwater resources in Perth and occurs to the south of the city between the Swan-Canning River and the Serpentine River. It covers an area of about 760 km^2 and is a shallow sand aquifer, formed by sediments deposited over the last 2 million years, with a saturated thickness of up to 40 m (Water and Rivers Commission, 2004). Its crest is about 18 km south of Perth's central business district (Water and Rivers Commission, 2004). A combination of high recharge rates through the Bassendean Sands and a topographic rise produce the Jandakot Mound, an apparent swell in the watertable reaching 27 m A.H.D. (Murdoch University, 1994).

In the Bannister Creek site, groundwater flowing westwards from the Jandakot Mound has a fall from 12 m A.H.D. to 3 m A.H.D. (Murdoch University, 1994). Bannister Creek is groundwater fed. In this area, the depth to the watertable is quite small so that much of the land is covered by a lattice of swamps with interconnecting damplands (Balla, 1994). This is becoming more obvious as the vegetation on the Jandakot Mound is cleared for housing developments, causing the watertable to rise (Balla, 1994).

2.2.4 Land Use History

The first land grants in Canning were taken up by European settlers in 1830 (Carden, 1991). Initial settlement was confined to the arable lands fringing the Canning River, which was important for its plentiful fresh water and its convenience as a transport link to Perth. For the next four decades growth in the Canning area was stagnant with only narrow strips being developed along the Albany Highway (Carden, 1991).

Early agriculture in the area consisted of rough grazing of stock and some market gardening, while early industry included timber cutting and quarrying relied on convict labour (Carden, 1991). Around the turn of the century the large land grants were broken up and intensive agriculture, including piggeries, dairying and poultry farming, proliferated. These rural activities continued well into the 1930s, before gradually disappearing with increasing residential subdivision and the movement of secondary industry to the area (Carden, 1991).

In the Bannister Creek area, urbanisation occurred rapidly during the 1960s and 1970s. Large areas of semi-rural land on the south of the Canning River were subdivided and this led to the development of the suburbs of Parkwood, Lynwood and Ferndale (Fisher, 1999).

The City of Canning is now predominantly an urban area, comprising industrial, commercial and residential uses, with a small area of rural land in the south. The City of Canning has low to medium housing density (25-30 houses per hectare). The older residential areas are generally less densely populated than the more recent residential developments. Commercial areas border the Albany Highway and are also dispersed throughout the district.

The Bannister Creek site is located in the suburb of Parkwood in the City of Canning. Parkwood was developed around the 1960s and 1970s with a low housing density (17 houses per hectare) at a minimum block size of around 571 m^2. Increasing urbanisation started from 1975. There were a total of 2,489 houses with a population of 6,673 people in 2001 and the average household size was three people. There are two schools located in this suburb, namely Parkwood Primary School and Lynwood Senior High School, and two community centres (Hossack Pavilion and Whaleback Community Centres) as well as three parks (Hossack Park, Vellgrove Park, and Willeri Park, which includes Whaleback Golf Course) (provided by the City of Canning).

2.3 Wanneroo Site

2.3.1 Location

The Wanneroo site (31° 45' S and 115° 48' E) is located about 35 km north of Perth CBD at approximately 20 m A.H.D. (Gentilli, 1998). The study site consisted of the catchment for the Munderee Place drains (piped outfall no 11) which empties into Lake Joondalup (see Figure 2.7). Lake Joondalup is situated in an interdunal depression on the Spearwood dune system (Bowra, Dooley, Williamson, Cluning, & Thomson, 2000; Ove Arup & Partners, 1994).

2.3.2 Landform

At the Wanneroo site there is a foundation bed of coastal limestone made up of aeolian calcarenite, variably lithified, kankerised and leached to quartz sand (Brittain, 1987). This is overlaid by the Spearwood Dunes, which consist of undulating terrain with limestone outcrops capped by secondary calcite overlain by a thin mantle of siliceous sand (McArthur & Bartle, 1980). The Tamala limestone lies 1-2 m below the surface (Brittain, 1987; Seddon, 1972).

The Spearwood Dunes lie west of the Bassendean Dunes and are younger with higher hills. Leaching and re-precipitation of lime cement has produced the characteristic limestone (Seddon, 1972). There are two principal soil associations within the formation; the

Karrakatta to the east and Cottesloe to the west. The Karrakatta underlies the study site, and is a deep yellow/brown sand with areas of exposed limestone.

The Spearwood Dunes consist of slightly calcareous aeolian sands with some fine organic material and iron. Having an appreciable iron content, the Spearwood Sands are yellow and brown in colour and are less leached than the pale grey sands of the Bassendean dunes (Seddon, 1972). Spearwood Sands generally have a Phosphorus Retention Index (PRI) of 7 (McArthur & Bettenay, 1974; McPharlin et al., 1990; Ritchie & Weaver, 1993).

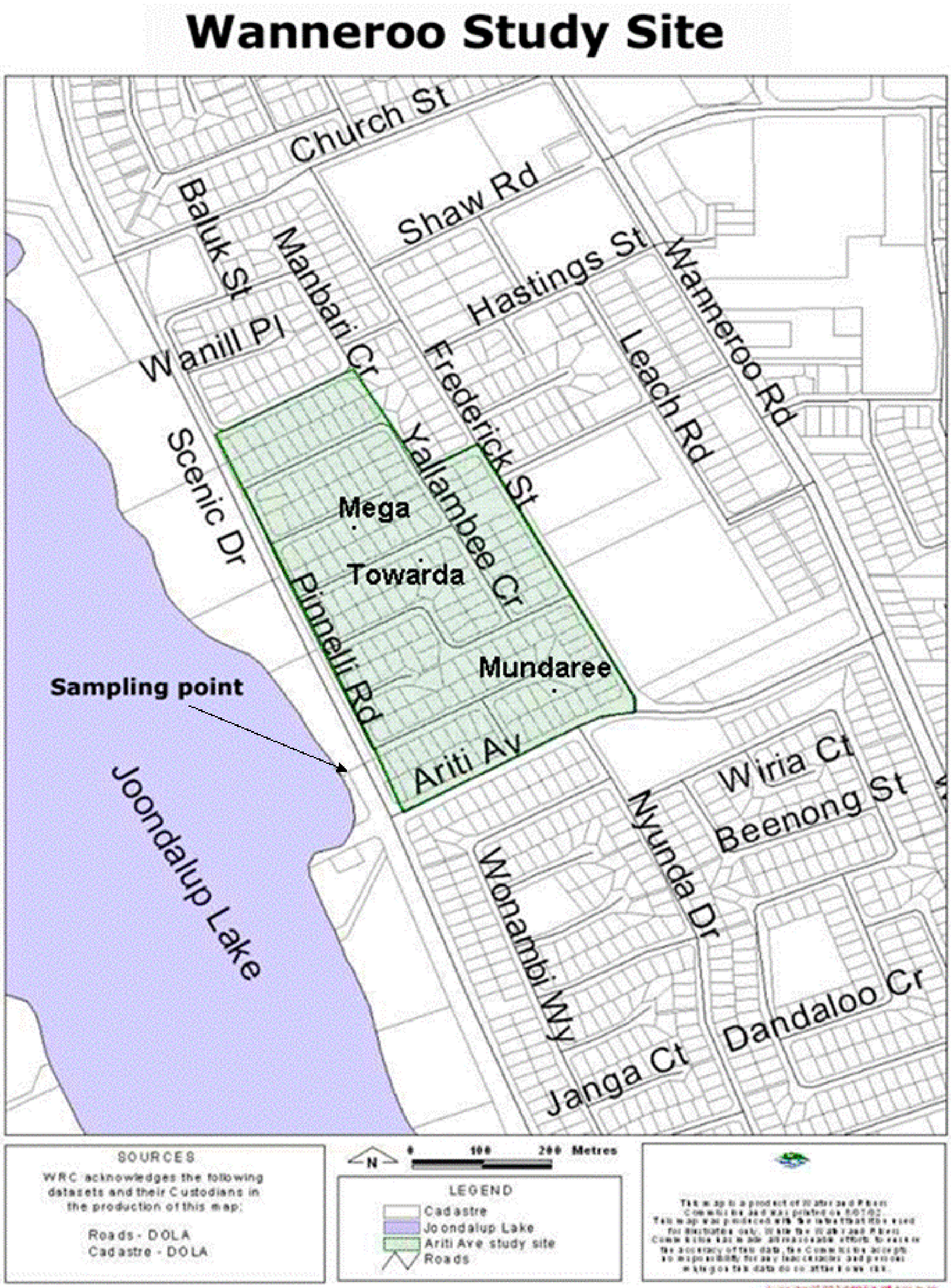


Figure 2.7 Wanneroo site (Supplied by the Department of Environment Western Australia).

Figure 2.8 Sampling point at Wanneroo

2.3.3 Groundwater

The Wanneroo site is located on the Gnangara Mound (Figure 2.4). The Gnangara Mound is one of the largest and most important aquifers in Western Australia (Water Authority of WA, 1995). It covers an area of about 2,140 km^2 and is a shallow sand aquifer, formed by sediments deposited over the last 2 million years, with a saturated thickness of up to 70 m (Water and Rivers Commission, 2004). Regional contour mapping of the Gnangara Mound area suggests that the average maximum groundwater level at the crest of the mound (between Muchea and Lake Pinjar) is about 75 metres above sea level. Based on this information, the groundwater drains towards the boundaries of the aquifer under the action of gravity and towards the Indian Ocean, Swan River, Ellen Brook and Gingin Brook (Western Australian Planning Commission & Water and Rivers Commission, 2001).

Lake Joondalup is directly connected to the groundwater, which lies in the pores between sand grains, pebbles and rock fractures (Balla, 1994). Groundwater flows from east to west across the Swan Coastal Plain, with steep gradients to the east of the linear lakes, such as Lakes Joondalup, Goollelal, and Neerabup, and very low gradients to the west. Congdon (1979) suggested that groundwater enters the lake through springs on the lake bottom.

Lake Joondalup lies between the coastal limestone ridge and the inland limestone ridge. It is not known how the depression formed. Some consider it a subsidence, others as a series of foundation faults, or calcified lime formations (Ian, 1981). The watertable levels along the lakes and swamps vary in height suggesting that they are expressions of the watertable of the Gnangara Mound (Brittain, 1987). They may therefore be a combination of these formations (Brittain, 1987; Congdon, 1979). The surrounds of the lake system rise gently on all sides giving the impression of a true lake formed by surface drainage into an impervious hollow. Considerable surface flow occurs from South to North between the lakes.

2.3.4 Land Use History

Initially, the European colonists camped close to the Swan and Canning Rivers (Martinick and Associates Pty Ltd, Gutteridge Haskins and Davey, & Brian Delfs and Associates, 1993). Their cattle and sheep were occasionally moved further north into the Wanneroo site just to the east of Lake Joondalup in search of better seasonal pasture. The land was primarily used as grazing runs; it is unknown if temporary camps were set up. The faeces of horses, cattle, sheep and other introduced animals would have begun to spread seeds from introduced species, many of which would in time become weeds. (Martinick and Associates Pty Ltd, Gutteridge Haskins and Davey, & Brian Delfs and Associates, 1993).

Between 1905 and 1969 horticulture increased in the area. The early farmers produced vegetables, fruit and grapes for the Perth market, but full scale market gardening did not begin until the early twentieth century. Arnold (1990) has mapped the dramatic changes in wetlands caused by clearing, grazing and market gardening. Water levels rose, causing the eventual abandonment of gardening around some lakes such as Lakes Joondalup, Goollelal and Neerabup, and weeds choked some of the smaller swamps. In particular, Lake Joondalup became a focus for increasing urbanisation, with the establishment of the Joondalup Regional Centre to the west of the lake (Stephenson, 1977).

By 1969 urbanisation had begun on the southern boundary of the Wanneroo site and rapidly increased. The population of Wanneroo expanded rapidly from 1975 and by 1993 had reached over 200,000 and is expected to be around 450,000 by 2021 (City of Wanneroo, 1993). Concurrent with this growth in population, market gardens have moved to the north of Wanneroo. Farm lots are being more intensively used and the pressure from subdivision is likely to continue. Housing estates have caused the most dramatic change on the environment and substantial development of land to the west of Wanneroo Road is expected to continue in accordance with Metroplan (State Planning Commision, 1987).

The City of Wanneroo also includes industrial development. The first light to medium industrial site was at Gnangara in Landsdale in 1972, followed by the development of the Wangara industrial estate in 1976 (Firkins, 1979).

The City of Wanneroo is expected to continue to change because of the spread of housing, intensive rural use and industrial/ commercial development. The environment will be interspersed by managed parklands and reserves which will provide a patchwork pattern to what will become a built environment (State Planning Commision, 1987). The Wanneroo site was developed as early as 1842 based on a surveyor recorded ‘road to Wanneroo’ and in August 1907 a government town site was gazetted as ‘Wanneru’.

In 2004 there were a total of 3,373 houses with a total population of 10,725 people and the average household size was three people within the City of Wanneroo. The housing density has been determined by the number of houses per hectare and is equal to 10 houses per hectare, which is a low housing density. There are four schools located in this suburb, namely East Wanneroo Primary, Wanneroo Primary, St Anthony School and Wanneroo Senior High School, and two community facilities, namely Wanneroo Recreation Centre and Aquamotion (provided by the City of Wanneroo).

CHAPTER 3: METHODS

Inputs, pathways and discharge of water, for the nutrients nitrogen and phosphorus, and suspended sediment from two small residential catchments were compared over a 1 year period between 11 April 2002 and 31 May 2003. Inputs into the catchment were assessed through a series of questionnaires completed by local residents. In addition selected inputs were estimated from the literature and local experts. Discharge from the catchment was assessed through a detailed sampling program that allowed quantification of loads of nutrients and sediments. Transport pathways between inputs and the drain were inferred from the combined data set.

3.1 Inputs

3.1.1 Questionnaire

3.1.1.1 Questionnaire Design

Inputs of nitrogen and phosphorus into each catchment by residents were assessed using a questionnaire (Appendix 1.1). The questionnaire was structured as follows: collection month, street address, water usage, fertiliser application, carwash and pet waste disposal. A pilot test of the questionnaire was undertaken to examine questions for correct interpretation, variation in response, redundancy, timing, and respondent interest. Approximately 25 households in each catchment were sampled, feedback noted, and the questionnaire was then modified to address issues raised.

3.1.1.2 Questionnaire Procedure

Ethics approval for the questionnaire was granted from the Human Research Ethics Committee at Edith Cowan University (Ethics Codes: 02-74) for the period of this project. Before conducting the interview, a disclosure form and informed consent for Research (Appendix 1.2 and 1.3) were provided to the respondents. Respondents were informed of the purpose of the study and that the outcomes and recommendations of this study would be helpful for a better understanding of stormwater pollution caused by their modern lifestyle. They were also advised of the right of privacy (anonymity) and if, for any reason, they felt uncomfortable with the study, they had the right to decline to participate at any time. To protect the respondent's right of privacy, the data were treated with the strictest confidence, and subjects were not identified by name in any report.

3.1.1.3 Questionnaire Sampling

The Bannister Creek site consists of 799 households, and the Wanneroo site of 203 households. A multi-stage cluster sampling was chosen for the questionnaire (Lawrence Neuman, 2006). Each study area was divided into different street areas or clusters. For each selected cluster, a list of households was developed. Households were then sampled randomly within each cluster until sufficient households had agreed to participate in the study. In this study, 230 households in total were sampled (67 in Wanneroo and 167 in Bannister Creek) representing about 25% of potential households in each catchment. The pilot test aims to improve the designed questionnaire to be easily understandable and precisely before conducting the larger household survey.

3.1.1.4 Questionnaire Survey

The questionnaire was administered on a monthly basis. The first time each questionnaire was filled out by the interviewee. I remained with them to answer any questions. After that, another questionnaire sealed in a plastic bag was left with the same respondent to fill out by her / himself for the following month. They then placed the completed form in the plastic bag provided, in a secure location near the mailbox at the end of the month. At the end of each month the questionnaire was collected and replaced with a new questionnaire. This process was continued for twelve months between June 2002 and May 2003. Once all the questionnaires were collected, all data were entered into the computer for further analysis. Microsoft Excel software has been used to key all raw data into the computer and they were treated and analysed by using basic values of statistics such as frequency, percentage, min, max, range, mean, median, correlation, standard deviation and standard error.

3.1.2 Groundwater Sampling

Three houses in each catchment that used groundwater to water their gardens were selected at random to assess the contribution of groundwater to nutrient inputs. At each house, 15 plastic containers (15 × 15 × 9 cm) were placed at random in each of the lawn and garden areas prior to watering (Figure 3.1). After watering, the depth of water in each container was measured and used to estimate the total volume of water applied by multiplying the average depth measured from the plastic container with the areas of lawns and gardens that were watered. Water from the containers was composited for analysis of chemical parameters. Water from each bore at the three houses in both Bannister Creek (at Glencairns:G site, Keslake:K site and Ritson street: R site as shown in Figure 2.5) and Wanneroo (at Mega: Me site, Mundaree Mu site, and Towarda street T site as shown in Figure 2.7) was collected on a monthly basis from October 2002 to May 2003 (In winter, few houses used groundwater on their gardens and so no samples were collected).

Figure 3.1 Groundwater sampling

3.1.3 Rainwater Sampling

Rainfall samples were collected in a clean (acid washed) plastic (15 × 15 × 9 cm) container exposed only during rainfall events throughout the year. Rainwater was collected at the Edith Cowan University campus in Joondalup (located <1 km from the Wanneroo study site). This water was assumed to be the representative of rainwater samples of both study sites. In the study, the average concentration of all rainwater samples was used in estimation of nutrient input loads into a catchment for both sites.

3.1.4 Water Sample Measurement

At each sampling time, physico-chemical parameters such as pH, salinity, conductivity, temperature, turbidity, dissolved oxygen, and redox potential were measured *in situ* using a calibrated multiparameter meter (Yeo-Kal Model 611 Intelligent Water Quality Analyser). A 250 mL aliquot of groundwater and rainfall water samples was frozen for later analysis of TN and TP. Another aliquot of known volume was filtered through 0.45 µm pretreated glass fibre filter paper. The pretreated filter paper was then frozen for later determination of total suspended solids (TSS) and loss on ignition (LOI) and 250 mL of filtrate was frozen for later determination of Filterable Reactive P (FRP), NH_3, and NOx (nitrate + nitrite).

3.1.5 Catchment Area and Land Use Measurements

Aerial photographs of each catchment and drainage maps were used to determine the catchment area. A clean plastic overlay was then used to trace out land uses including roof area, footpath area, driveway plus paved area, road area, and lawn plus garden area. Each area was measured from the tracings using WinDIAS software (Delta-T Devices LTD) with an image grabber board (a leaf area measurer) connected to a colour video camera.

3.2 Outputs

3.2.1 Stormwater

3.2.1.1 Stormwater Sampling

The discharge from each catchment and concentrations of nutrients and total suspended solids (TSS) were measured between April 2002 and May 2003. Sampling involved targeting regular monitoring, seasonal 24 hour sampling and storm events. This system was used because all sampling had to be done manually due to the unavailability of automated samplers and the vandalism of passive samplers.

As the drain in Bannister Creek flowed throughout the year (Figure 2.6), water samples were collected at regular intervals (Mondays, Tuesdays and Thursdays). At the Wanneroo site, the drain only flowed during and shortly after rainfall (Figure 2.8) therefore water samples were collected as frequently as possible when the drain was flowing. Once every season, samples were collected from the Bannister Creek drain at hourly intervals for 24 hours. At Wanneroo, water was only briefly flowing for one of the 24 hour sampling events (1 September 2002) and only 5 samples were collected from 11.00 hrs to 18.00 hrs as a result. A series of storm events was targeted and 11 samples (6 samples at Wanneroo and 5 samples at Bannister Creek) from 3 storm events (one event at Wanneroo on 11 April 2003 and two events at Bannister Creek on 9 August and 14 September 2002) were collected at high frequency (approximately 4 to 6 times within 20 to 30 minute average 1 time per 5 minutes for this study) during the events. In particular, sampling was intensified during the rising limb and reduced during the peak and falling limb. To capture the rising limb would be difficult due to a delay of upto 1 hour in attending sites during rain events.

3.2.1.2 Measurement of Stormwater Sample

At each sampling time, physico-chemical parameters such as pH, salinity, conductivity, temperature, turbidity, dissolved oxygen, and redox potential were measured *in situ* using a calibrated multiparameter meter (Yeo-Kal Model 611 Intelligent Water Quality Analyser). The depth of flow (stage height) was also measured. Grab samples of water were collected. A 250 mL aliquot from each sample was frozen for later analysis of TN and TP. Another aliquot of known volume was filtered through 0.45 μm preweighed glass fibre filter paper. The filter paper was then frozen for later determination of TSS and LOI and the filtrate frozen for later determination of FRP, NH_3, and NOx (nitrate + nitrite).

The cross-section of each drain was measured in relation to the stage height and the flow velocity was measured by flow meter (Model C.M.C 20 Current Meter Counter available from Hydrological Services P/L Sydney Australia). Between 19 August 2002 and 11 December 2002, a depth sensor and logger (Odyssey environmental data recording systems, Dataflow Systems Pty Ltd) was installed at the Bannister Creek drain. The Wanneroo drain was not suited to installation of a depth sensor.

3.3 Analysis of Samples

All sample containers and glassware were acid washed for at least 2 hours in a 10% HCl acid bath, and then rinsed twice in double deionised water prior to use.

3.3.1 TN and TP Analysis

TN and TP were measured on an autoanalyser (Skalar Model SAN^{plus} System Digital Sampler SA1000) following digestion by persulphate oxidation as modified from Hosomi and Sudo (1986). Modifications included autoclaving of 10 mL of oxidising reagent (0.113M NaOH-0.07M $K_2S_2O_8$) and 20 mL of sample in a 30 mL polycarbonate screw capped vessel at 120ºC for one hour before slowly bringing back to atmospheric pressure.

3.3.2 NOx, NH_3 and FRP Analysis

The digestate was then analysed for NOx and FRP. NOx was analysed using a cadmium reduction method as per Skalar methods (undated) as modified from APHA (1998). FRP was analysed using the ammonium molybdate solution method as per Skalar (undated) (methods as modified from APHA (1998). Ammonia was analysed fluorometrically (Turner Instruments Fluorometer Model 10-AU-005-CE Fluorometer) using the methods of Holmes et al. (1999).

3.3.3 TSS Analysis

The filter paper for TSS samples was pretreated by drying it at 50 ^{o}C in an oven for 12 hrs, cooling the filter paper in a desiccator for several hours to prevent the paper from drawing moisture from the surroundings and then weighing it.

TSS samples were dried to constant weight at 80 ^{o}C, then weighed. Loss on ignition was subsequently determined by ashing the filter paper at 550 ^{o}C for 2 hours, cooling and then spraying with double deionised water; the filter paper was then dried at 80 ^{o}C until a constant weight was reached.

3.4 Analysis of Data

3.4.1 Discharge

3.4.1.1 Bannister Creek

Discharge at Bannister Creek was calculated using both the Manning equation and a runoff coefficient. This is because the water depth of the culvert was measured three times a week. The water depths were assumed to remain constant between sampling times. Rainfall during this intervening period was not included in the discharge. To attempt to include rainfall events, a runoff coefficient was introduced to estimate the amount of rainfall added to the discharge.

Discharge in the drain was determined by using equation 3.1 (below). At Bannister Creek, low flows prevented the use of propelled velocity meters and so velocity was estimated from the depth based on the Manning formula (equation 3.2 (LMNO Engineering, 2004).

$$Q = vA \qquad \text{Equation 3.1}$$

$$v = k/n\ (2A/\theta d)^{2/3}\ S^{1/2} \qquad \text{Equation 3.2}$$

Derived from equations 3.3 to 3.7

$$A = d^2/8\ (\theta - \mathrm{Sin}\theta) \qquad \text{Equation 3.3}$$

$$R = A/P \qquad \text{Equation 3.4}$$

$$P = \theta d / 2 \qquad \text{Equation 3.5}$$

$$\theta = 2\mathrm{Cos}^{-1}(1-2y/d) \qquad \text{Equation 3.6}$$

$$v = k/n\ R^{2/3}\ S^{1/2} \qquad \text{Equation 3.7}$$

Where :

A = Cross-sectional area of the drain containing the discharge in m^2

d = Culvert diameter in m which was 1.20 m.

k = Unit conversion factor = 1.0

n = Manning coefficient. In this study, the culvert surface of both study sites was finished concrete which has an n value of 0.012.

P = Wetted perimeter in m. P is the contact length (in the cross-section) between the water and the culvert.

Q = Discharge or flow rate in $m^3\ s^{-1}$.

R = Hydraulic radius of the flow cross-section in m.

S = Slope of channel bottom or water surface. The slope of the drains was obtained from the City of Canning and the City of Wanneroo. At Bannister Creek the drain slope is 1 m over 104 m and at Wanneroo the drain slope is 1 m over 188 m. Therefore, the slopes for the Bannister Creek and Wanneroo sites were 0.0096 and 0.0053 respectively.

v = Velocity of the water in $m\ s^{-1}$

y = Water depth measured (perpendicular) to the bottom of the culvert in m. As the culvert has a small slope (S), entering the vertical depth introduces only minimal error.

θ = Angle representing how full the culvert is in radians. A culvert with θ = 0 radians (0^o) contains no water, a culvert with θ = pi radians (180^o) is half full, and a culvert with θ = 2 pi radians (360^o) is completely full.

The daily discharge was based on the water depth (y) in the culvert as measured in the regular sampling program. From this, θ was determined using equation 3.6, by substituting y and the culvert diameter (d). After that θ was substituted into equation 3.3 to determine the flow cross-sectional area (A). Equation 3.2 was then used to determine the velocity of the water (v). Discharge (equation 3.1) was then converted to daily discharge.

The runoff coefficient was determined by using the depth sensor (installed adjacent to the culvert between 19 August 2002 and 11 December 2002) which recorded the water depth at 10 minute intervals (Figure 3.2). The depth sensor measurements were converted to match the other depth data. A linear regression of depth sensor vs measured depth was produced ($y = 0.085x – 12.57$; $r^2 = 0.868$) and used to adjust the depth sensor measurements. A series of discrete storm events were identified from the sensor data and matched to rainfall data (provided by Sandra Hall, postgraduate student, who had installed a continuous rain gauge near the study site).

Figure 3.2 Depth Sensor Installation

Discharge during the event was determined using the Equations 3.1 and 3.2. The ratio of the total volume of rain landing on the catchment to the discharge was used to produce an average runoff coefficient of 0.25.

Daily rainfall figures provided by Sandra Hall (postgraduate student) and Julie Roberts (Coordinator of Bannister Creek Catchment Group) from close to the catchment were then used with the runoff coefficient to determine stormwater discharge which was then added to the daily discharge to determine the total discharge during the study period.

3.4.1.2 Wanneroo

Discharge calculations at Wanneroo used only a runoff coefficient. The runoff coefficient was determined by targeting a storm event and measuring the depth (y) of flow over time in the culvert, and the rainfall throughout the storm event. Then the Manning equation was used to determine the storm event discharge. The ratio of the volume of stormwater discharged from the culvert to the total rainfall volume falling on the catchment at the same period of storm event was determined, to produce the runoff coefficient of 0.13. Daily rainfall figures from Ian Foster (Agriculture Western Australia) were then used with the runoff coefficient to determine stormwater discharge from the catchment at the drain outfall.

3.4.2 Input Load Estimation

This study attempted to determine the load of nitrogen and phosphorus added to each catchment. To achieve this, the following factors were identified for each input examined.

(1) Proportion of households sampled providing an input to the catchment.

(2) The frequency and/or duration of each activity.

(3) The amount of nitrogen and phosphorus produced each time.

Once these parameters were extracted from the questionnaires, load was quantified, as detailed below (see Appendix 3 Input Load Estimation).

3.4.2.1 Phosphorus Input from Car Washing

The amount of cleaning detergent (carwash detergent and dishwashing detergent) used in this study per wash was estimated from the recommended amount on the detergent product labels. This varied from 10 to 60 mL time $^{-1}$, however the most frequently used amounts were 10 mL, 20 mL and 30 mL in general brand names. This study assumes that amount of detergent used was equal to 20 mL time^{-1} or g time^{-1} as this was the median quantity. According to the Australian Ecolabel Program: Australian Voluntary Environmental

Labelling Standard “Hand Dishwashing Detergents” (Draft Standard No: 17-2004), phosphorus concentrations in detergents do not exceed 25 mg L^{-1}. Therefore, each car washed on a hard surface area resulted in a maximum of 0.5 mg of phosphorus entering into the residential catchment. The nitrogen content of detergents was considered minimal and was not calculated.

3.4.2.2 Fertiliser Applications

The amount of fertiliser used in each study area was determined from the questionnaires. It includes a total of all types of fertiliser applied on lawns, gardens and pot plants. The fertilisers reported in this study included potting mix and mulch because they contained nutrients or fertilisers.

The N: P ratio of the main fertiliser brands reported (Baileys, Scotts, Richgro and Yates) were averaged to 13.5:3.6, which was used in the calculations.

3.4.2.3 Inputs from Reticulation and Garden Watering

Nutrient input load from groundwater usage was estimated by multiplying the concentration of nutrients in groundwater and the volume of groundwater used in the catchment.

The amount of groundwater used by hoses at each study site can be quantified by multiplying the flow rate of the hoses, the duration of use, frequency of use and proportion of houses using groundwater. In this study the flow rate was determined by measuring the volume of water running from the hoses in a certain time. This was done at a few households and an average figure of 10 L min^{-1} was determined. This figure was used in the calculations.

The amount of groundwater used in reticulation at each study site was estimated by measuring the length of time watering occurred and the average depth of coverage per time.

Nutrient input load from groundwater usage was estimated by multiplying the concentration of nutrients in groundwater and the volume of groundwater used in the catchment.

3.4.2.4 Estimation of Nutrient Input Load from Pet Waste

The composition of cat and dog faeces is similar, with the faeces containing about 0.7% nitrogen (N), and 0.25% phosphate; urine contains about 1.1% N, and 0.01% P_2O_5 (Hall & Schulte, 1999).

The amount of nitrogen and phosphorus from dog excreta was provided by Dr Nick Costa of Murdoch University cited in Hall & Schulte (1999). The size of dogs in the study sites varied from small to large (Table 3.1). This study selected the medium size for dogs and small size of dogs or cats as being representative. The estimation of nutrient load from pet waste was based on the nitrogen and phosphorus content of typical dog foods and the digestibility of nitrogen in a dog's system as shown below.

Table 3.1 Quantity of nitrogen and phosphorus in pet waste

Size of Dog	Faeces (g N d^{-1})	Urine (g N d^{-1})	Total Waste (g N d^{-1})
Average dog = 20 kg	1.92	2.67	4.59
Small dog or cat = 4 kg	0.52	0.71	1.23
large dog = 60 kg	4.3	6.04	10.34
	Faeces (g P d^{-1})	Urine (g P d^{-1})	Total Waste (g P d^{-1})
Average dog = 20 kg	0.12	0.03	0.15
Small dog or cat = 4 kg	0.024	0.006	0.003
large dog = 60 kg	0.36	0.09	0.45

Other pets recorded in the questionnaires were birds, chickens, guinea pigs, fish and rabbits. It was considered that waste from these animals was likely to be small or unlikely to enter the drainage network.

3.4.2.5 Estimation of Nutrient Input Load from Rainwater

Nutrient input load from rainwater was estimated by multiplying the concentration of nutrients in rainwater and the volume of rainwater landing on the catchment.

3.4.2.6 Estimation of NOx Input Loads from Vehicle Exhaust

NOx input loads were estimated by multiplying the wind rose contribution factor, traffic volume, number of vehicles and the amount of NOx produced by vehicles within a certain distance in each the study site.

The wind rose contribution factor was created by using wind speed and wind direction sector percentage collected by the Department of Environment from its base stations nearest to the study sites during the period: 1 June 2002 to 31 May 2003 inclusive. It was taken into consideration to adjust the real amount of load input of NOx loads entering the study area.

At the Bannister Creek study site, the data at South Lake A.Q. M. S. station from Department of Environment were summed for wind directions from the N, NNE, NE, ENE, E, ESE, SE, NW, and NNW (details in Table 3.2). Only these directions were taken into consideration because they would blow the NOx produced by vehicles entering the study site. Wind rose contribution factor at this site between June 2002 and May 2003 was equal to 41.7%.

At the Wanneroo study site, the data at Cullacabardee M.S. station from Department of Environment were summed for wind directions from the N, NNE, NE, ENE, E, ESE, SE, SSE, and NNW (details in Table 3.2). Only these directions were taken into consideration because they would blow the NOx produced by vehicles entering the study site. Wind rose contribution factor at this site between June 2002 and May 2003 was equal to 45.4%.

Traffic volume supplied by Main Roads Western Australia indicates the number of cars travelling past a certain point on the street within a 24 hour period. Average traffic volume at the Wanneroo study site between 2001 and 2003 was equal to 14,600 vehicles d^{-1} and average traffic volume at the Bannister Creek study site between 2001 and 2002 was equal to 13,425 vehicles d^{-1}.

This traffic volume was then broken down into vehicle classifications based on the "AUSTROADS Vehicle Classification System" (Table 3.3).

Percentages of each vehicle classification at Wanneroo were C1 (89.1%) C2 (2.75%) C3 (2.7%) C4 (0.8%) C5 (0.6%) C6 (0.1%) C7 (2.2%) C8 (0.2%) C9 (1%) C10 (0.1%) C11 (0.3%) C12 (0.2%) and at Bannister Creek they were C1 (92.7%) C2 (2.3%) C3 (1.8%) C4 (0.5%) C5 (0.3%) C6 (0.2%) C7 (1.3%) C8 (0.1%) C9 (0.6%) C10 (0.1%) C11 (0.1%) C12 (0.15%). These figures were supplied by Main Roads Western Australia.

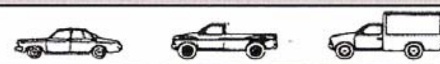
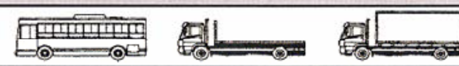
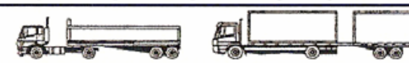
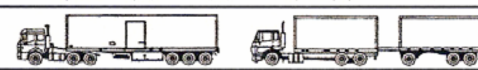
The amount of pollution generated by different types of vehicle was taken from techniques used to estimate the emissions from vehicles for the National Pollutant Inventory (see **www.npi.gov.au** for more information on NPI)

Table 3.2 Wind speed – wind direction percentage occurrence matrix at Bannister Creek and Wanneroo between June 2002 and May 2003

Wind Speed	Wind Direction Sector																																	
	N		NNE		NE		ENE		E		ESE		SE		SSE		S		SSW		SW		WSW		W		WNW		NW		NNW		Total	
Range (m/s)	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN
Over 13.5																																	0.0	0.0
12.0-13.5																																	0.0	0.0
10.5-12.0																										0.1							0.0	0.1
9.0-10.5																							0.1		0.1	0.2							0.2	0.3
7.5-9.0																				0.1	0.2	0.1	0.3	0.1	0.1	0.2		0.1			0.1		0.8	0.8
6.0-7.5			0.1	0.1		0.1		0.2	0.3	0.1	0.1	0.2		0.1			0.1	0.1	0.3	0.8	1.3	1.1	0.8	0.6	0.3	0.5	0.1	0.4	0.2	0.1	0.1		3.8	4.6
4.5-6.0	0.2	0.2	0.3	0.3	0.2	0.5	0.2	0.7	1.1	1.0	0.7	1.4	0.1	0.5		0.3	0.3	0.9	1.5	2.2	3.7	3.3	1.6	1.9	0.8	1.3	0.4	1.0	0.5	0.3	0.3	0.1	12.0	15.7
3.0-4.5	0.7	0.6	0.9	0.4	0.9	1.2	1.1	1.4	2.8	2.2	1.9	3.0	0.7	1.7	0.6	1.1	1.3	2.7	2.7	2.7	4.4	2.9	2.7	2.4	1.7	1.4	0.8	0.8	0.9	0.5	0.7	0.5	24.9	25.7
1.5-3.0	1.6	1.6	2.3	0.8	1.4	1.2	1.5	1.3	2.3	2.0	2.0	2.7	1.4	2.6	2.8	2.8	4.1	3.1	2.7	2.7	2.2	2.0	2.0	1.6	1.1	1.2	0.9	0.7	0.9	0.8	0.8	0.9	30.2	28.0
0.5-1.5	1.0	1.8	1.4	1.4	2.2	1.4	3.2	1.3	2.9	1.5	1.9	1.7	1.7	2.2	2.9	1.9	2.7	1.2	1.1	0.8	0.7	0.8	0.6	0.8	0.4	0.9	0.5	1.1	0.5	1.3	0.6	1.4	24.5	21.7
Totals	3.6	4.2	5.1	3.0	4.7	4.4	6.2	5.0	9.4	6.8	6.5	9.0	3.9	7.1	6.4	6.1	8.5	8.1	8.4	9.4	12.6	10.2	8.1	7.4	4.6	5.8	2.8	4.1	3.1	3.2	2.7	3.0	96.4	96.9
Calm (<0.5 m/s)	3.5%	3.2%																																
Data Recovery	100%	87.2%																																
Sample Time	10 mins	10 mins																																

Table 3.3 AUSTROADS Vehicle Classification System

AUSTROADS Vehicle Classification System

Level 1 Length (indicative) Type	Level 2 Axles and Axle Groups: Axles	Level 2 Axles and Axle Groups: Groups	Level 3 Vehicle Type: Typical Description	AUSTROADS Classification: Class	AUSTROADS Classification: Parameters	AUSTROADS Classification: Typical Configuration
			LIGHT VEHICLES			
Short up to 5.5m		1 or 2	**Short** Sedan, Wagon, 4WD, Utility, Light Van, Bicycle, Motorcycle, etc	1	d(1) $\leq$ 3.2m and axles = 2	
Medium 5.5m to 14.5m	3, 4 or 5	3	**Short - Towing** Trailer, Caravan, Boat, etc	2	groups = 3 d(1) $\geq$ 2.1m, d(1) $\leq$ 3.2m, d(2) $\geq$ 2.1m and axles = 3, 4 or 5	
			HEAVY VEHICLES			
	2	2	**Two Axle Truck or Bus**	3	d(1) > 3.2m and axles = 2	
	3	2	**Three Axle Truck or Bus**	4	axles = 3 and groups = 2	
	> 3	2	**Four Axle Truck**	5	axles > 3 and groups = 2	
Long 11.5m to 19.0m	3	3	**Three Axle Articulated** Three axle articulated vehicle, or Rigid vehicle and trailer	6	d(1) > 3.2m, axles = 3 and groups = 3	
	4	> 2	**Four Axle Articulated** Four axle articulated vehicle, or Rigid vehicle and trailer	7	d(2) < 2.1m or d(1) < 2.1m or d(1) > 3.2m axles = 4 and groups > 2	
	5	> 2	**Five Axle Articulated** Five axle articulated vehicle, or Rigid vehicle and trailer	8	d(2) < 2.1m or d(1) < 2.1m or d(1) > 3.2m axles = 5 and groups > 2	
	$\geq$ 6	> 2	**Six Axle Articulated** Six axle articulated vehicle, or Rigid vehicle and trailer	9	axles = 6 and groups > 2 or axles > 6 and groups = 3	
Medium Combination 17.5m to 36.5m	> 6	4	**B Double** B Double, or Heavy truck and trailer	10	groups = 4 and axles > 6	
	> 6	5 or 6	**Double Road Train** Double road train, or Medium articulated vehicle and one dog trailer (M.A.D.)	11	groups = 5 or 6 and axles > 6	
Large Combination Over 33.0m	> 6	> 6	**Triple Road Train** Triple road train, or Heavy truck and three trailers	12	groups > 6 and axles > 6	

Definitions:
Group: Axle group, where adjacent axles are less than 2.1m apart
Groups: Number of axle groups
Axles: Number of axles (maximum axle spacing of 10.0m)

d(1): Distance between first and second axle
d(2): Distance between second and third axle

Table 3.4 Amount of NOx generated by different types of vehicles

Types of Vehicles	NOx g km^{-1}
Petrol car (4, 6 or 8 cyl)	1.78
LPG car (4, 6 or 8 cyl)	1.2
Petrol ute/van/4WD	1.7
Diesel ute/van/4WD	1.4
Diesel truck	8.7
Petrol motorcycle	0.6

Based on this information (Table 3.4), all vehicles classified as class C1 and C2 had their NOx emissions averaged to a rate of 1.52 g km^{-1}. All vehicles classified as class C3 to C12 are assumed to produce NOx at the rate of 8.7 g km^{-1} because they are all heavy vehicles considered to equate with trucks.

The distance at which the traffic passed by the study sites was approximately 600 m and 400 m for Wanneroo and Bannister Creek respectively. This figure was acquired from measuring the distance the traffic passed by the study site in the Perth Street Directory and then scaling with meters provided. This distance was used to quantify the portion of NOx entering the catchment after it was emitted from the exhaust.

3.4.3 Output Load Quantification

The Wanneroo site showed that there was no contribution to the stormwater drain from groundwater baseflow and the flow only occurs following sufficient rains. The load therefore simply varies with the volume of water discharged from the catchment over time and the concentration of nitrogen and phosphorus in the water.

The Bannister Creek site includes groundwater flow. To quantify the output load from stormwater alone at this study site, the groundwater flow load was taken into consideration. In this case, the output load (L_O) was equal to the total output load (L_T) minus the groundwater flow load (L_{GW}).

$L_O = L_T - L_{GW}$ Equation 3.8

L_T was determined by multiplying the total daily discharge by the measured nutrient concentration. Nutrient concentrations for those days when samples were not collected were assumed to be the same as the previous concentration measured. Therefore, this assumes that the concentration from a single grab sample is representative of nutrient concentrations during the intervening period.

L_{GW} was estimated by multiplying flows on days of no rainfall (assuming base flow conditions) with the average nutrient concentration of the base flow during the summer period from December 2002-February 2003 (when there was no rain event).

CHAPTER 4: NUTRIENT INPUT

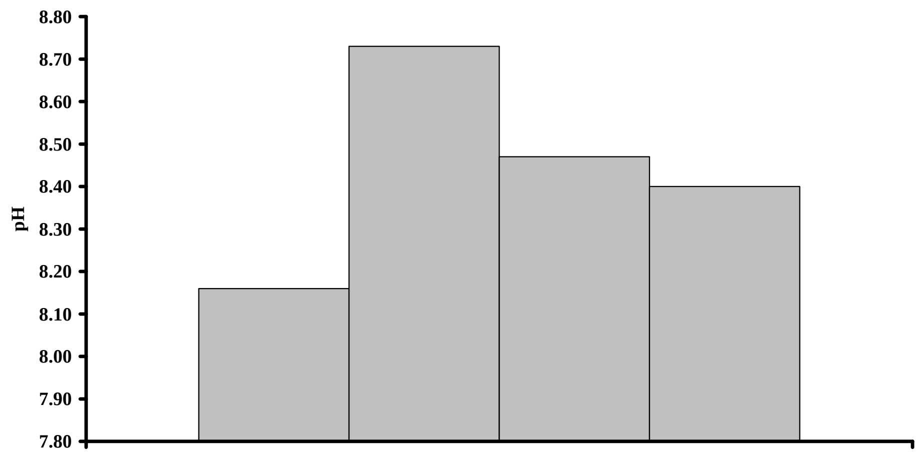
Nutrient input into the Bannister Creek and Wanneroo sites comes mainly from rainfall and household activities such as fertiliser application, groundwater usage for reticulation and garden watering, car washing, vehicle emissions from transportation and pet waste disposal. The sources of nutrients in stormwater are often difficult to determine since, in urban residential areas, most are non-point sources. Therefore the questionnaire approach was used to collect the nutrient input into the catchment through household activities. Apart from that collecting of rainwater samples for nutrient concentration analysis and secondary data in the literature also was used to examining of nutrient input load into the catchment which is one of the aims of the research study. This research study has attempted to identify sources and to quantify amounts used on catchments through residential questionnaires and other available data to estimate nutrient input load into the catchment.

4.1 Rainwater

Rainwater was collected at the School of Natural Science (Edith Cowan University) at Joondalup, within 2 km of Wanneroo. It was assumed to be representative of rainwater at both study sites.

The pH of rainwater samples was alkaline (8.16-8.73) and conductivity varied between 85 $\mu S\ cm^{-1}$ and 257 $\mu S\ cm^{-1}$ (Figure 4.1).

a) pH



b) Conductivity

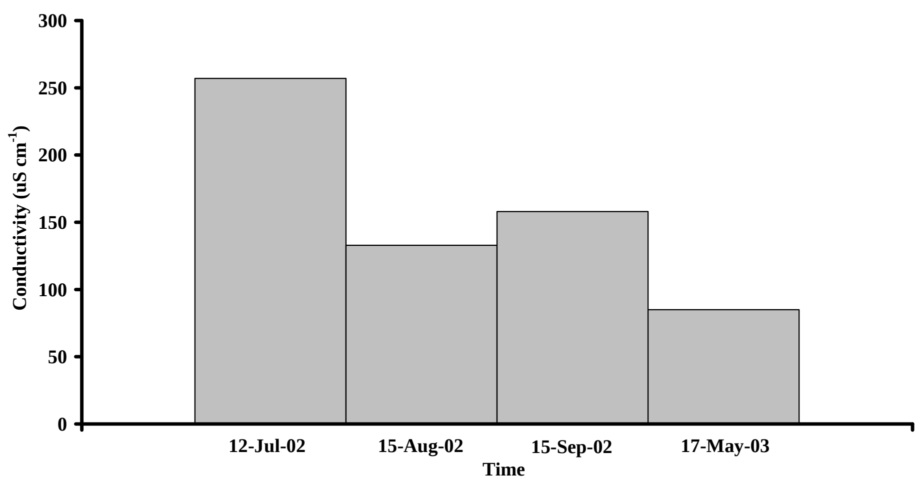


Figure 4.1 pH and conductivity of rainwater measured at Edith Cowan University between July 2002 and May 2003.

The TN concentrations of rainwater samples varied from a minimum of 0.049 mg L^{-1} to a maximum of 0.452 mg L^{-1} with a mean of 0.268 ± 0.12 (95% Confidence Interval) mg L^{-1} (Figure 4.2a). NH_4 concentrations varied from a minimum of 0.002 mg L^{-1} to a maximum of 0.246 mg L^{-1} with a mean of 0.097 ± 0.07 (95% Confidence Interval) mg L^{-1} (Figure 4.2b). NOx concentrations varied from 0.002 mg L^{-1} to a maximum of 0.121 mg L^{-1} with a mean of 0.056 ± 0.05 (95% Confidence Interval) mg L^{-1} (Figure 4.2c). Interestingly, all N concentrations peaked on the 15 August 2002.

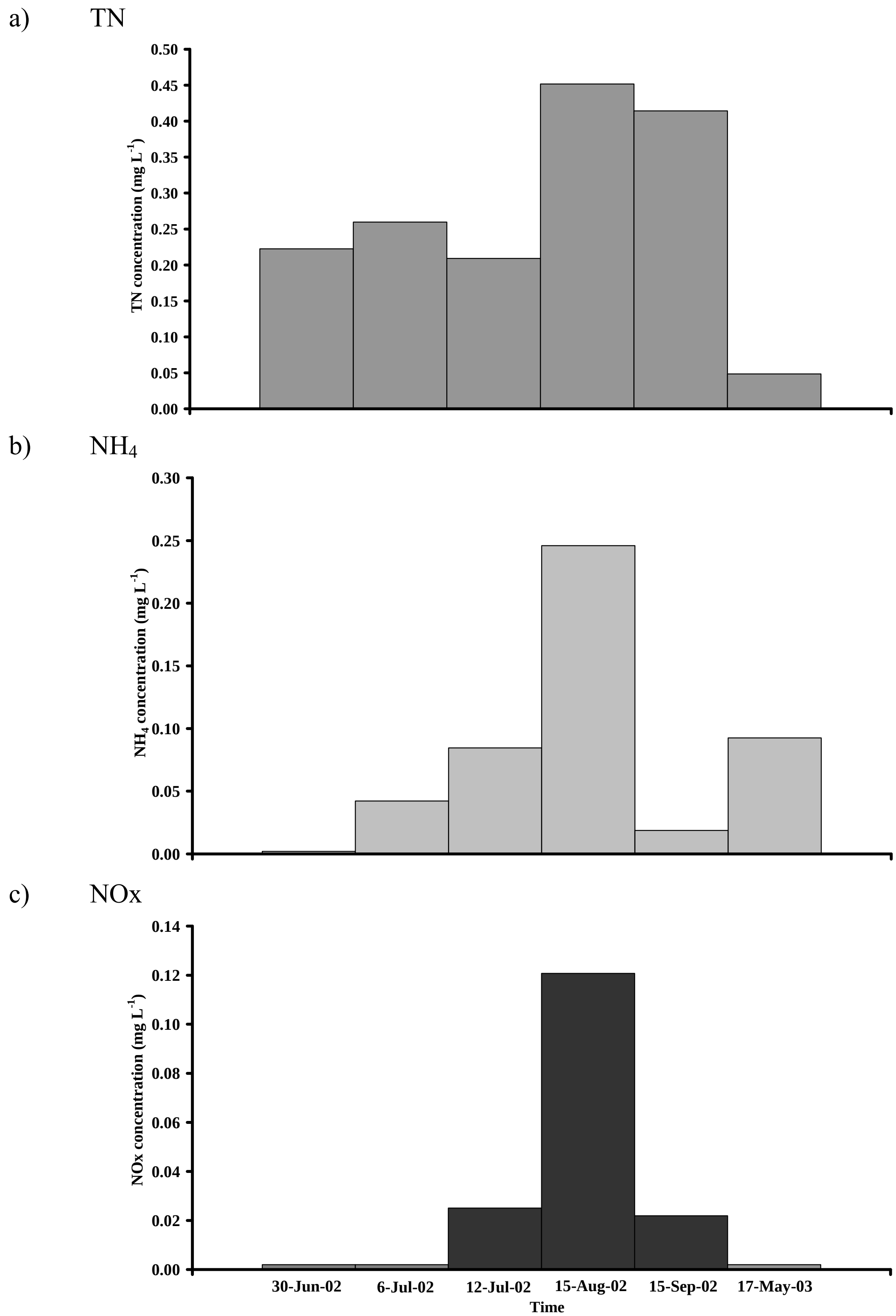


Figure 4.2 TN, ammonium (NH_4) and NOx concentrations of rainwater collected at Edith Cowan University between June 2002 and May 2003.

The TP concentration of rainwater varied from a minimum of 0.008 mg L^{-1} to a maximum of 0.054 mg L^{-1} with a mean of 0.022 ± 0.01 (95% Confidence Interval) mg L^{-1} (Figure 4.3a). FRP concentrations varied from 0.004 mg L^{-1} to 0.068 mg L^{-1} with a mean of 0.018 ± 0.02 (95% Confidence Interval) mg L^{-1} (Figure 4.3b). The TP concentrations peaked in the month after those of TN (15 September 2002) suggesting that there are real differences between rainfall events rather than a one-off contamination of the sample. The TSS concentration varied from a minimum of 0.2 mg L^{-1} to 5 mg L^{-1} with a mean of 2.52 ± 1.83 (95% Confidence Interval) mg L^{-1} (Figure 4.3c).

Despite the variability in rain nutrient concentrations between sample times, confidence intervals were small and so the mean was used to estimate nutrient loads.

The TN input load from rainwater was high in the winter months (June, July, August 2002 and May 2003) at over 19 mg $month^{-1}$ m^{-2} at both sites and gradually dropped in the spring months (September, October, November 2002, and March and April 2003) to < 16 mg $month^{-1}$ m^{-2} at both sites. It dropped to the lowest level in the summer months (December 2002, January and February 2003) when it varied between 0-3.5 mg $month^{-1}$ m^{-2} at both sites (Figure 4.4).

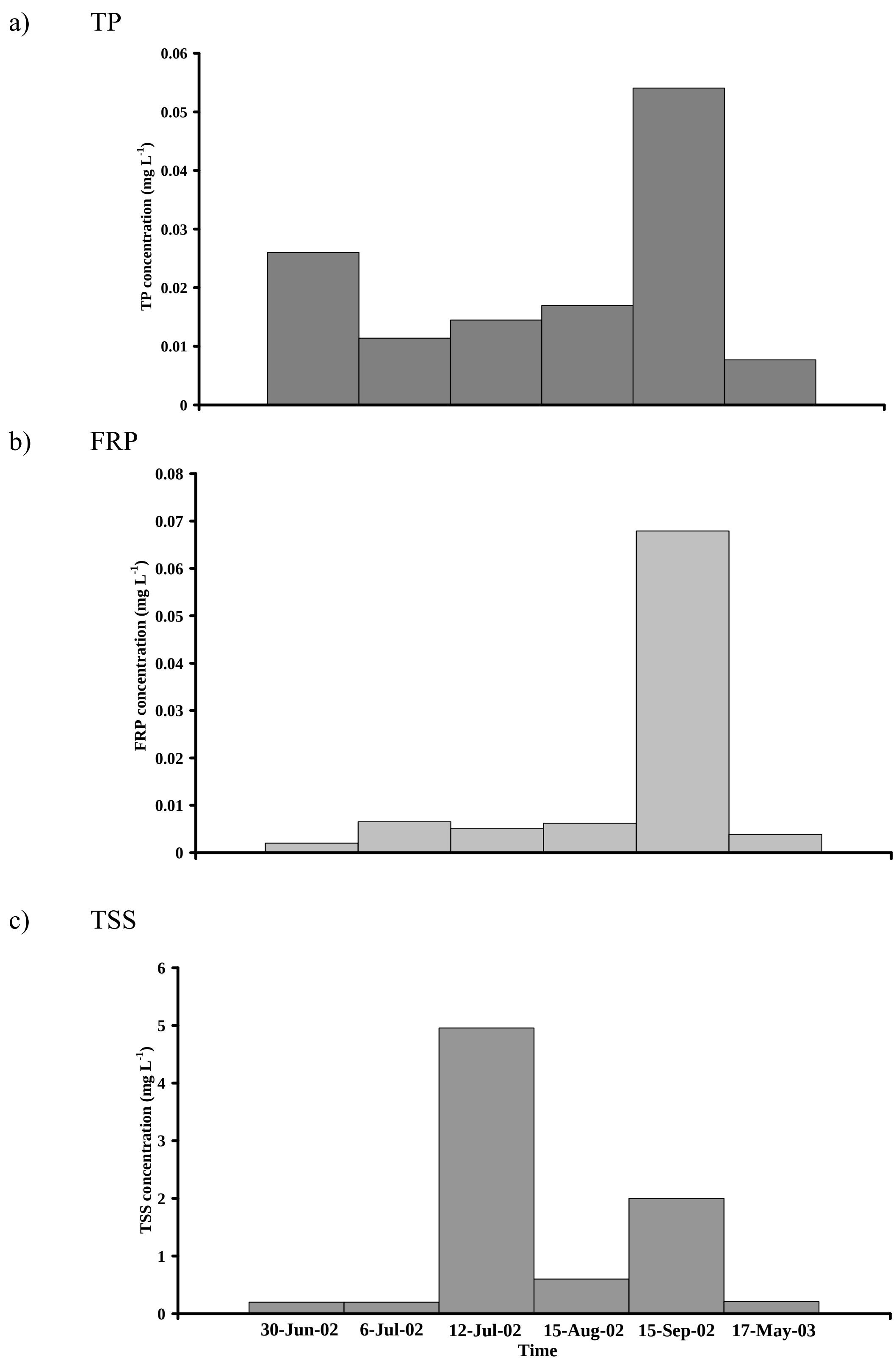


Figure 4.3 TP, FRP and TSS concentrations of rainwater collected at Edith Cowan University between June 2002 and May 2003.

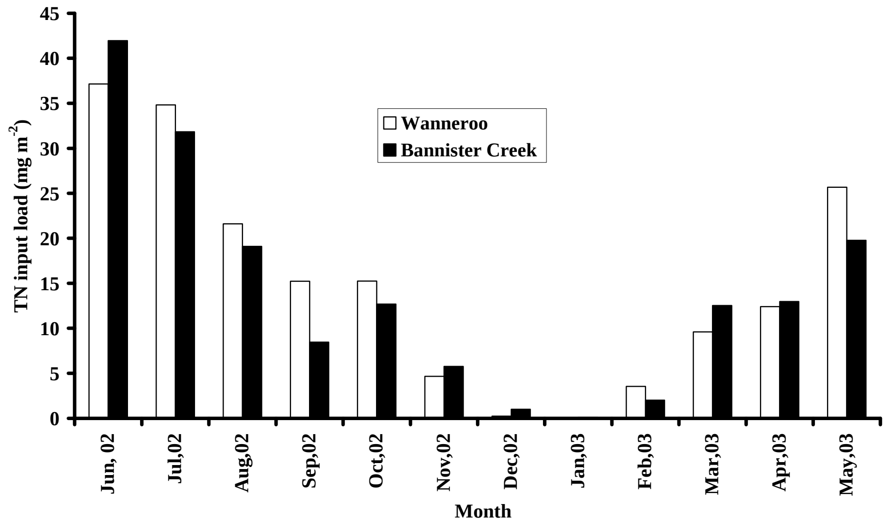


Figure 4.4 TN input load from rainwater at Bannister Creek and Wanneroo between June 2002 and May 2003.

The TP input load from rainwater was high in the winter months (June, July, August 2002 and May 2003) at over 1.55 mg month^{-1} m^{-2} at both sites and gradually dropped in the spring/autumn (September, October, November, 2002 and March and April 2003) to < 1.5 mg month^{-1} m^{-2}. It dropped to the lowest level in the summer months (December 2002 and January and February 2003) when it ranged between 0 and 0.29 mg month^{-1} m^{-2} at both sites (Figure 4.5).

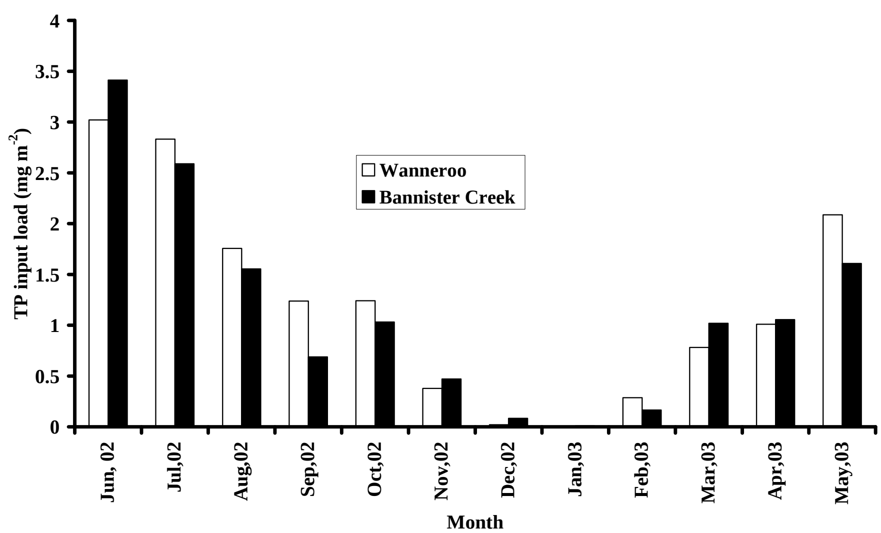


Figure 4.5 TP input load from rainwater at Bannister Creek and Wanneroo between June 2002 and May 2003.

The TSS input load from rainwater was high in the winter months (June, July, August 2002 and May 2003) at over 176 mg month^{-1} m^{-2} at both sites, gradually dropped in the spring months (September, October, November, 2002 and March and April 2003) to < 79 mg month^{-1} m^{-2} before dropping to the lowest level in the summer months (December 2002 and January and February 2003) when it ranged between 0 and 33 mg month^{-1} m^{-2} at both sites (Figure 4.6).

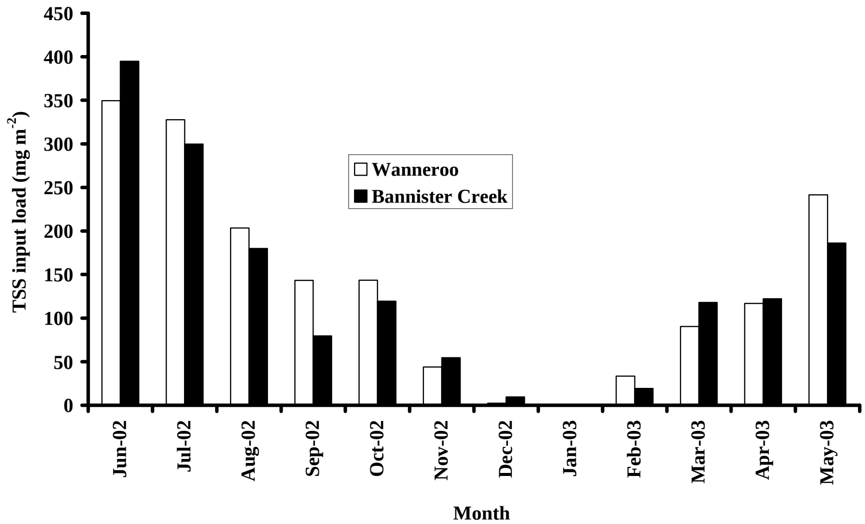


Figure 4.6 TSS input load from rainwater at Bannister Creek and Wanneroo between June 2002 and May 2003.

4.1.1 *Accuracy of Rainwater Concentration Estimation*

The accuracy of the estimation for rainwater concentration can be assessed by averaging the rain concentration of the total rain sample to determine how much the rain concentration of the samples collected at a rain event deviated from the average of rain concentrations. By comparing the rain concentration of a sample collected at the rain event to the average rain concentrations. An indication of the potential uncertainty in the estimation for rain concentration could be achieved (Table 4.1).

Table 4.1 The percentage that nutrient concentration in rainwater input loads could have been over-estimated or under-estimated by comparing the rain concentration of a sample collected at the rain event to the average rain concentrations.

Date	TN	NH4	NOx	TP	FRP	TSS
% OVER ESTIMATE						
30-Jun-02		100	100		100	100
6-Jul-02		56	100	48	63	100
12-Jul-02		13	55	34	71	
15-Aug-02	41			22	65	76
15-Sep-02	35	81	61			21
17-May-03		4	100	65	78	100
% Mean	38	51	83	42	76	79
% UNDERESTIMATE						
30-Jun-02	17			16		
6-Jul-02	3					
12-Jul-02	22					49
15-Aug-02		61	54			
15-Sep-02				60	74	
17-May-03	82					
% Mean	31	61	54	38	74	49

Table 4.1, reveals an average overestimation of rain concentrations for six rain events of 42% for TP, 83% for NOx, 38% for TN, 51% for NH_4, 76% for FRP and around 79% for

TSS. Nutrient loads were more likely to be overestimated than underestimated except for TP and TN.

4.2 Fertiliser Application

Between June 2002 and May 2003 forty nine (78%) households at Wanneroo and 128 (76%) households at Bannister Creek applied fertiliser at least once to their gardens. The survey found that the mean amount of fertiliser applied to lawn / garden beds / pot plants was 9.2 kg month^{-1} house^{-1} at Wanneroo and 5.7 kg month^{-1} house^{-1} at Bannister Creek.

The percentage of households that applied fertiliser to their gardens each month varied between sites and over the year (Figure 4.7). It was high at over 10% during the winter months (June, July, August, 2002 and February to May 2003) and rose to over 20% in the spring and summer months (September 2002 to January 2003). The maximum percentage of households applying fertiliser was 35% in September 2002 at Wanneroo and 35 % in October 2002 at Bannister Creek.

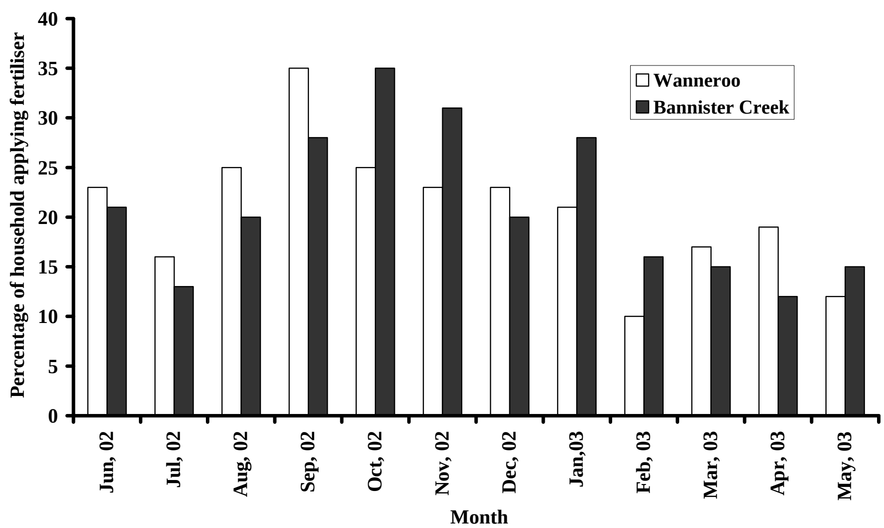


Figure 4.7 Monthly percentage of households applying fertiliser to gardens at Wanneroo and Bannister Creek.

The amount of fertiliser applied to lawns / garden beds / pot plants was highest in June 2002 at 44 kg house^{-1} in Wanneroo and in January 2003 at 15 kg house^{-1} in Bannister Creek (Figure 4.8). Most fertiliser was applied in June 2002, September to November 2002, and January 2003 at > 5 kg house^{-1}. During the remainder of the year < 7 kg house^{-1} was applied at both sites. The mean amount of fertiliser applied was 5.7 ± 1.27 kg month^{-1} house^{-1} at Bannister Creek and 9.23 ± 3.53 kg month^{-1} house^{-1} at Wanneroo.

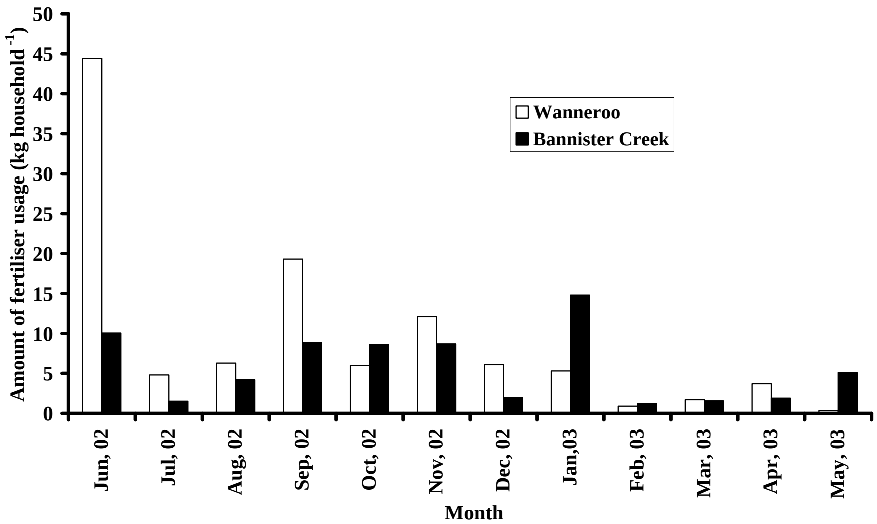


Figure 4.8 Amount of fertiliser applied to lawns, garden beds and pot plants.

The amount of fertiliser applied to lawns, garden beds and pot plants can be divided into two types; chemical fertiliser and organic fertiliser (Table 4.2).

Table 4.2 Type and amount of fertiliser applied in Bannister Creek and Wanneroo between June 2002 and May 2003

Date	Wanneroo (kg household^{-1})		Bannister Creek (kg household^{-1})	
	Chemical Fertiliser	Organic Fertiliser	Chemical Fertiliser	Organic Fertiliser
Jun, 02	3.38	41.05	0.68	9.36
Jul, 02	1.88	2.88	0.57	0.96
Aug, 02	0.87	5.39	0.48	3.73
Sep, 02	0.23	19.03	1.39	7.45
Oct, 02	0.56	5.41	1.84	6.76
Nov, 02	0.88	11.18	1.99	6.69
Dec, 02	0.39	5.74	0.41	1.55
Jan, 03	0.30	4.98	1.75	13.05
Feb, 03	0.25	0.61	0.34	0.87
Mar, 03	0.08	1.61	0.48	1.08
Apr, 03	0.43	3.32	0.15	1.76
May, 03	0.09	0.27	0.26	4.86
Mean ± se	0.78 ± 0.28	8.46 ± 3.32	0.86 ±0.20	4.84 ± 1.13

At Bannister Creek, the TN input load from fertiliser applications ranged from 61 kg month^{-1} in February 2003 to 546.5 kg month^{-1} in January 2003. At Wanneroo, the TN input load from fertiliser applications peaked in the early winter at around 378.5 kg month^{-1} in June 2002, and 138.9 kg month^{-1} in September 2002. The loads gradually decreased during the summer to < 42.8 kg month^{-1}.

TN input load from fertiliser application varied from 0.08 to 0.68 kg month^{-1} house^{-1} with a mean (± se) of 0.28 ± 0.04 kg month^{-1} house^{-1} at Bannister Creek and from 0.02 to 1.86 kg month^{-1} house^{-1} with a mean (± se) of 0.39 ± 0.37 kg month^{-1} house^{-1} at Wanneroo. The majority of TN input loads at Bannister Creek were lower than at Wanneroo from June to December 2002 except for October 2002, January, February and May 2003 (Table 4.3).

Table 4.3 TN input load from fertiliser application at Bannister Creek and Wanneroo between June 2002 and May 2003

Month	TN input load from fertiliser (kg household $^{-1}$)	
	Wanneroo	Bannister Creek
Jun, 02	1.86	0.41
Jul,02	0.35	0.11
Aug,02	0.30	0.19
Sep,02	0.68	0.44
Oct,02	0.26	0.48
Nov,02	0.50	0.50
Dec,02	0.25	0.11
Jan,03	0.21	0.68
Feb,03	0.05	0.08
Mar,03	0.07	0.10
Apr,03	0.17	0.08
May,03	0.02	0.20
Mean ± se	0.39 ± 0.37	0.28 ± 0.04

At Bannister Creek, TP input load from fertiliser use was variable ranging from 17.80 kg month^{-1} in February 2003 to 168.6 kg month^{-1} in January 2003. The mean of TP input load equalled 69±14.74 kg month^{-1}. At Wanneroo TP input load from fertiliser use ranged from 1.30 kg month^{-1} in May 2003 to 119.1 kg month^{-1} in June 2002. The mean of TP input load equalled to 25±13.6 kg month^{-1}.

The TP input load per household ranged from 0.01 kg month^{-1} house^{-1}at both sites to 0.21 kg month^{-1} house^{-1}at Bannister Creek and 0.59 kg month^{-1} house^{-1}at Wanneroo (Table 4.4).

Table 4.4 TP input load from fertiliser application at Bannister Creek and Wanneroo between June 2002 and May 2003

Month	TP input load from fertiliser (kg household^{-1})	
	Wanneroo	Bannister Creek
Jun, 02	0.59	0.13
Jul, 02	0.10	0.03
Aug, 02	0.09	0.06
Sep, 02	0.22	0.13
Oct, 02	0.08	0.14
Nov, 02	0.16	0.15
Dec, 02	0.08	0.03
Jan, 03	0.07	0.21
Feb, 03	0.02	0.01
Mar, 03	0.02	0.03
Apr, 03	0.05	0.03
May, 03	0.01	0.06
Mean ± se	0.12 ± 0.12	0.08 ± 0.01

4.3 Household Use of Ground or Tap Water

Tap water was not considered a significant source of nutrients or TSS to catchment discharge. However washing down of driveways and pathways or garden watering with tap water provides a potential transport pathway into the drainage network for nutrients/sediments that have accumulated on these surfaces.

The surveys showed that a total of 76 (46%) and 21 (33%) of households hosed down their driveways and pathways to clean them with a mean of 2.94 and 1.2 times house^{-1} yr^{-1} at Bannister Creek and Wanneroo respectively.

At Bannister Creek and Wanneroo the majority of households only washed their driveways once per year but at Bannister Creek one individual did it 153 times yr^{-1} (Figure 4.9).

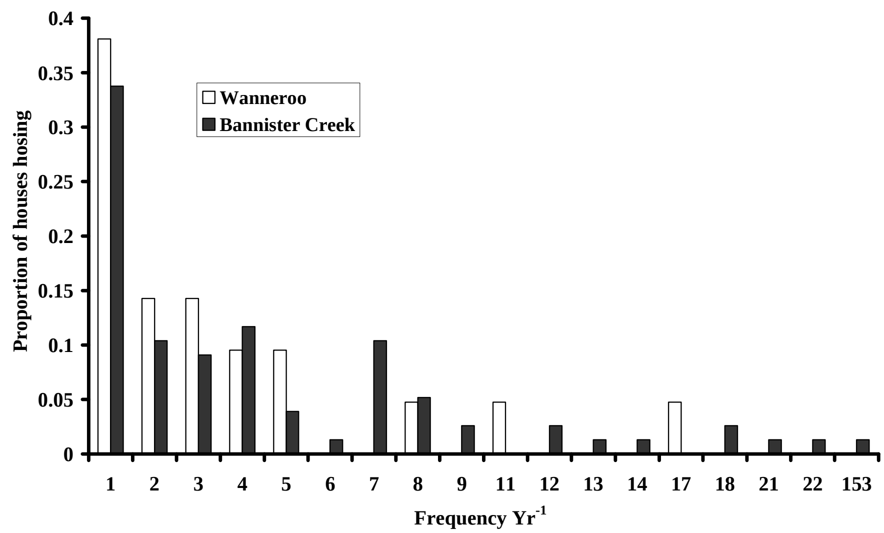


Figure 4.9 Proportion of houses and their frequency in hosing down the driveway / pathway.

At Wanneroo, most hosing down of driveways and pathways occurred during late spring to early autumn with a frequency per household of 0.1 to 0.06 times household^{-1} (Figure 4.10). The only exception was a high frequency in May 2003; however the cause of this is unknown. At Bannister Creek, most hosing down of driveways and pathways occurred between November 2002 and April 2003 with a frequency per household at over 0.25 times household^{-1}.

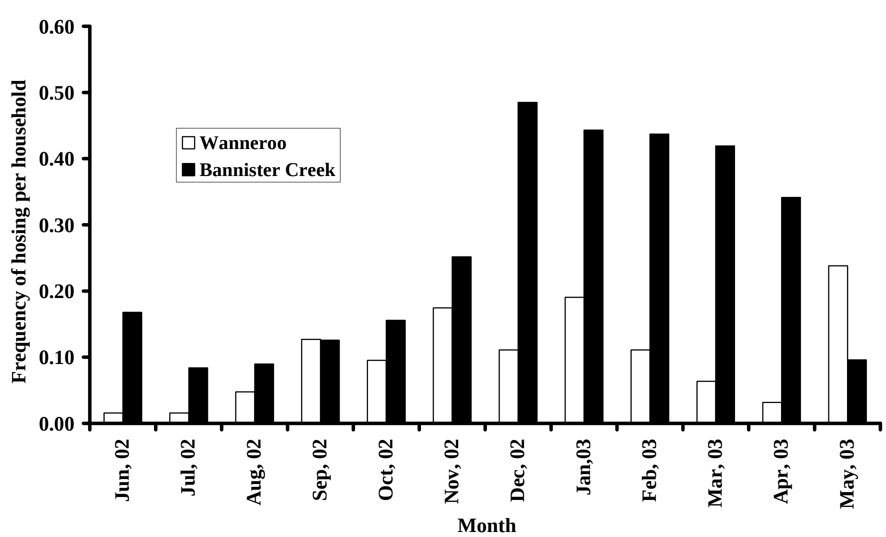


Figure 4.10 Frequency of hosing down the drive way / pathway at both study sites between June 2002 and May 2003.

4.4 Garden Watering

Over the year, there were 166 (100%) and 62 (98.4%) households watering lawns / garden beds / pot plants (gardens) at Bannister Creek and Wanneroo respectively.

In the winter months (June and July) less than 35% of households watered their gardens (Figure 4.11) but this rose to > 90% between November and March. There was little difference between Bannister Creek and Wanneroo.

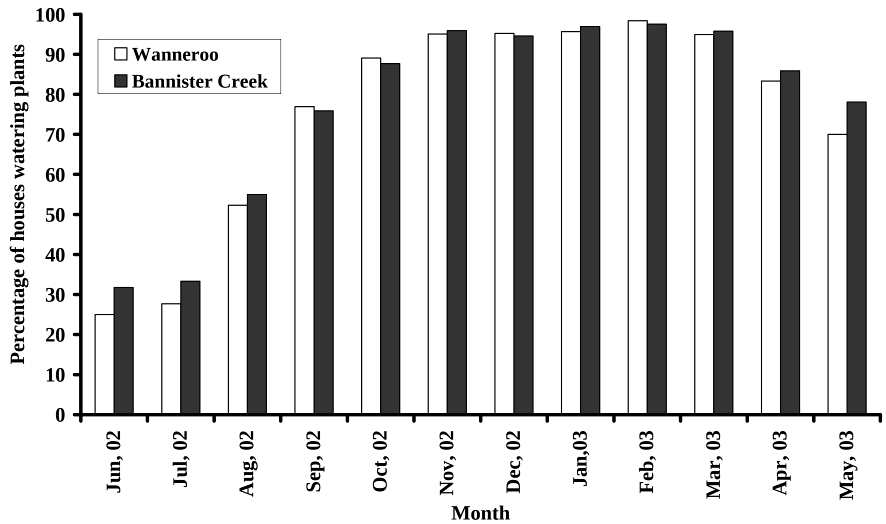
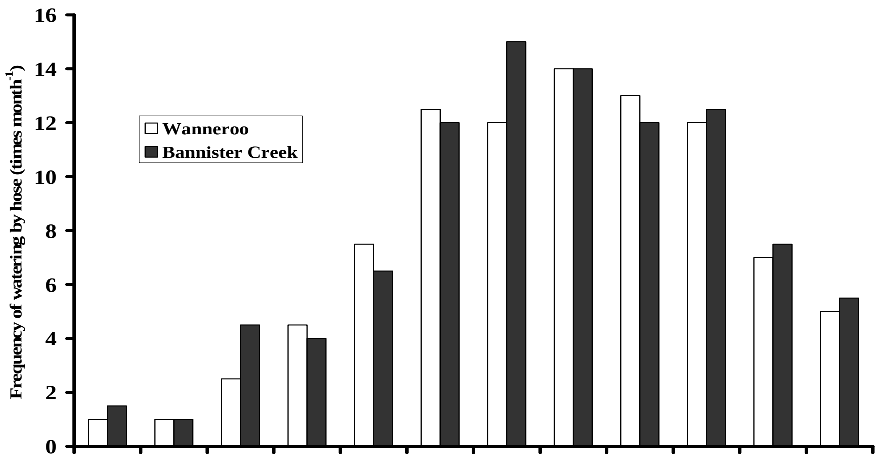


Figure 4.11 Percentage of households watering lawns, garden beds and pot plants.

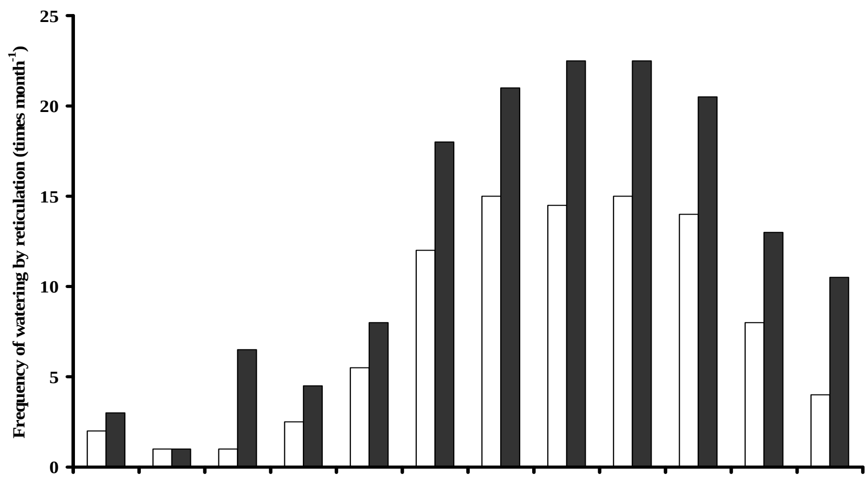
The frequency of watering gardens was less than 2 times month^{-1} house^{-1} in June and July 2002 (Figure 4.12a) but this rose to more than 10 times month^{-1} house^{-1} between November 2002 and March 2003. There was no apparent difference between Bannister Creek and Wanneroo.

Reticulation (using piped watering systems connected to scheme water or private groundwater bores) to water gardens was used less than 3 times month^{-1} house^{-1} in June and July 2002 but this rose to above 10 times month^{-1} house^{-1} between November 2002 and March 2003 at both sites (Figure 4.12b).

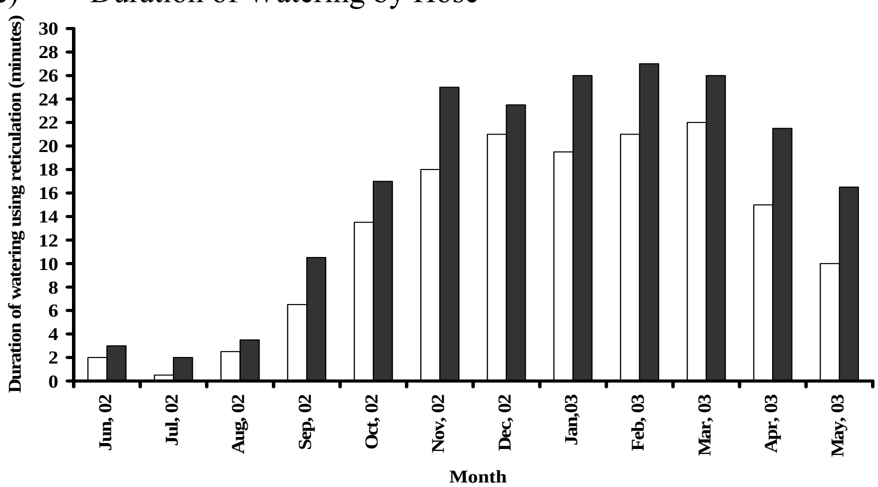
a) Frequency of Watering by Hose



b) Frequency of Watering by Reticulation



c) Duration of Watering by Hose



d) Duration of Watering by Reticulation

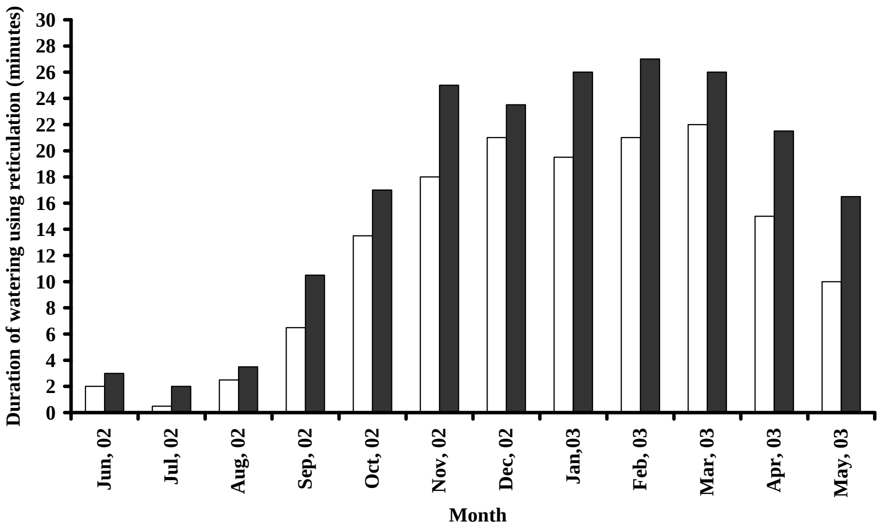


Figure 4.12 Monthly watering of gardens at Bannister Creek and Wanneroo with a) frequency of watering by hose, b) frequency of watering by reticulation, c) duration of watering by hose, d) duration of watering using reticulation.

The use of hoses for hand watering of gardens was less than 3 minutes occasion^{-1} month^{-1} house^{-1} in June and July 2002 but this rose to above 10 minutes occasion^{-1} month^{-1} house^{-1} between November 2002 and March 2003 with the same pattern at both sites (Figure 4.12c).

The reticulation was used to water gardens for less than 3 minutes occasion^{-1} month^{-1} house^{-1} in the winter months but this rose to above 18 minutes occasion^{-1} month^{-1} house^{-1} between November 2002 and March 2003 with the same pattern at both sites (Figure 4.12d).

The total quantity of water used in watering gardens was less than 14 m^3 month^{-1} household^{-1} in winter (Figure 4.13) but this rose to above 100 m^3 month^{-1} household^{-1} between November 2002 and March 2003 with the same pattern at both sites.

Cleaning and watering of gardens was generally dominated by the use of scheme water. This accounted for 50.8% and 53.3% of water used for cleaning driveways, 78.5% and 52.4% for lawns, 84.6% and 66.5% for garden beds and 92.5% and 82.9% for pot plants at Wanneroo and Bannister Creek respectively.

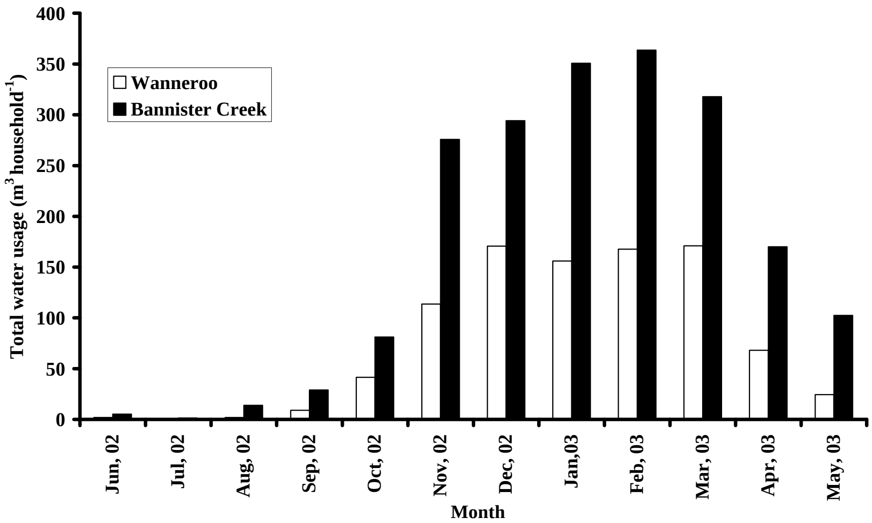


Figure 4.13 Total amount of water used monthly at Bannister Creek and Wanneroo between June 2002 and May 2003.

Groundwater was mainly used between November 2002 and April 2003 at both sites, although in Bannister Creek some use occurred throughout the year. TN input load from groundwater usage in winter was less than 7 g month^{-1} house^{-1} at both sites but rose to more than 155 g month^{-1} house^{-1} at Bannister Creek and 28 g month^{-1} house^{-1} at Wanneroo between November 2002 and March 2003. The difference in load between Bannister Creek and Wanneroo reflects the higher usage at Bannister Creek (Figure 4.14).

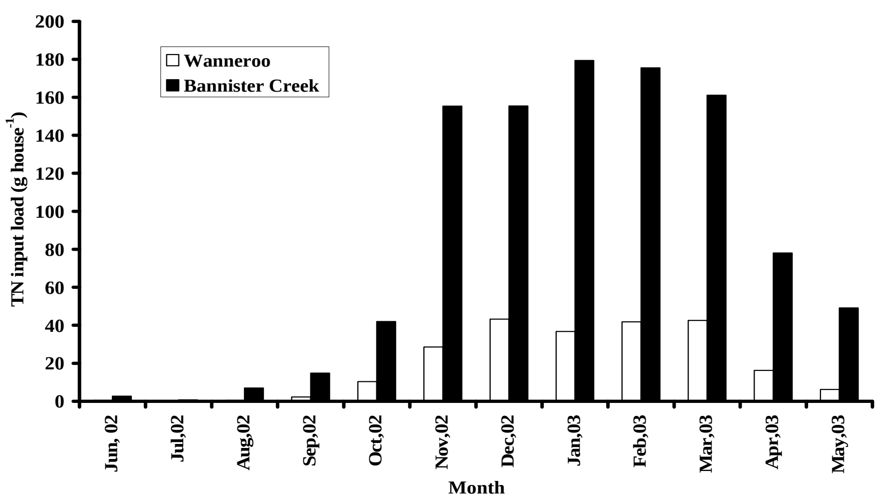


Figure 4.14 TN load from groundwater usage at Bannister Creek and Wanneroo between June 2002 and May 2003.

Groundwater usage and TP loading to the catchment were high between November 2002 and March 2003 at both sites, as these are the warmest months of the year. Winter usage was very low. The TP input load from groundwater usage varied from 0.48 g month^{-1} house $^{-1}$ at Wanneroo to 5.64 g month^{-1} house $^{-1}$ at Bannister Creek during peak usage (Figure 4.15).

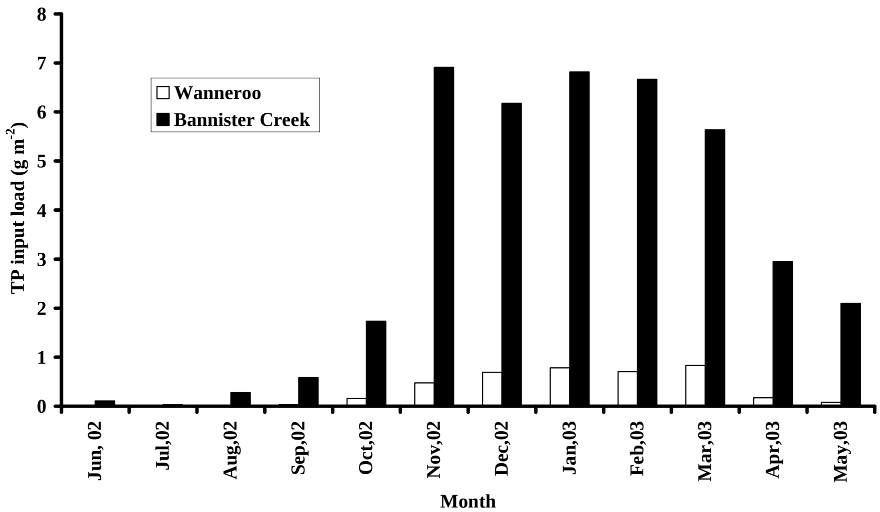


Figure 4.15 TP load from groundwater usage at Bannister Creek and Wanneroo between June 2002 and May 2003.

4.5 Vehicle Emissions

The TN load from vehicle emissions was considered to be constant for the whole period of the study; because it was based on data collected by the government agency responsible. Traffic volume and vehicle classification were obtained from the Main Roads Department, Western Australia, whereas the wind rose contribution factor and quantity of NOx emission rate from vehicles for the National Pollutant Inventory (see **www.npi.gov.au** for more information on NPI) were obtained from Department of Environmental Protection. The traffic volume, which was randomly collected at a specific time once during the year, was assumed to be the representative for the whole period of the study. This information was used to estimate TN load from vehicle emissions at each study site. It was estimated that 126 mg month^{-1} m^{-2} at Bannister Creek and 252 mg month^{-1} m^{-2} at Wanneroo of TN was emitted from car exhausts and this was assumed to be blown and deposited on the catchment (see Appendix 3 Input Load Estimation).

4.6 Pet Waste

Seventy three percent and eighty two percent of households in Bannister Creek and Wanneroo respectively had pets. The pets were mainly dogs, cats, and birds as shown in Table 4.5. The most numerous pets at both sites were birds, followed by fish, dogs and then cats.

Table 4.5 Type and number of pets

Pet	Wanneroo	Bannister Creek
	Number	Number
Dogs	47	118
Cats	39	79
Birds	184	165
Guinea pigs	1	3
Rabbits	1	9
Fish	51	120
Chickens	23	-

Pet waste was disposed of into rubbish bins or in the garden at > 38% of households at both sites. Pet waste disposal into the compost accounted for < 10% of households at both sites.

At both sites the TN load from pet waste disposal was considered to be constant for the whole period of this study as the number of pets did not change over the study period. It was equal to 19.5 kg month^{-1} catchment^{-1} at Bannister Creek and 7.24 kg month^{-1} catchment $^{-1}$ at Wanneroo. TP load from pet waste disposal was equal to 0.63 kg month^{-1} catchment^{-1} at Bannister Creek and 0.23kg month^{-1} catchment^{-1} at Wanneroo.

Over 38% of bin and garden disposal site is used for pet waste disposal at Bannister Creek and Wanneroo (Figure 4.16).

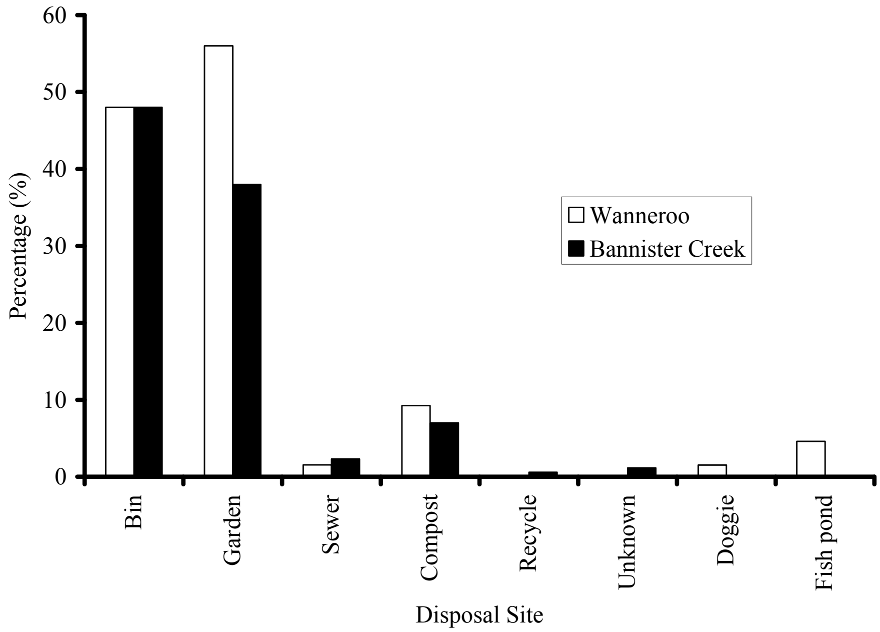


Figure 4.16 Percentage of disposal sites used for pet waste disposal at Wanneroo and Bannister Creek between 2002 and 2003.

4.7 Car Washing

The survey results on car washing during the study revealed that there were similar proportions of households at Bannister Creek (79%) and Wanneroo (72%) washing their cars at home.

The frequency of car washing was slightly higher at Bannister Creek than Wanneroo (8.2 and 5.7 times yr^{-1} $house^{-1}$ respectively). Cars were washed primarily on lawn areas at Bannister Creek (73%) and Wanneroo (70%). On the other occasions hard surfaces (such as driveways) were used.

Special car washing detergent was the most common form of detergent used, followed by dishwashing detergent, water alone and then hair shampoo (Bannister Creek only) (Table 4.5). Carwash detergent was used most at both sites, by 54% of households at Bannister Creek and 32% of households at Wanneroo, as shown in Table 4.6.

Table 4.6 Type of detergent used in car washing at Bannister Creek and Wanneroo between June 2002 and May 2003

Type of Detergent Use	Wanneroo	Bannister Creek
	Number (Percentage)	Number (Percentage)
Carwash detergent	23 (32 %)	91 (54 %)
Dishwashing detergent	16 (22 %)	41 (24 %)
Hair shampoo	0	1 (0.59 %)
Water	15 (21 %)	31 (18 %)

TP load from carwash detergents ranged between 0.01 mg house $^{-1}$ month^{-1} and 0.07 mg house $^{-1}$ month^{-1} (Figure 4.17) and was higher at Bannister Creek, except in June 2002. TN load was considered to be negligible.

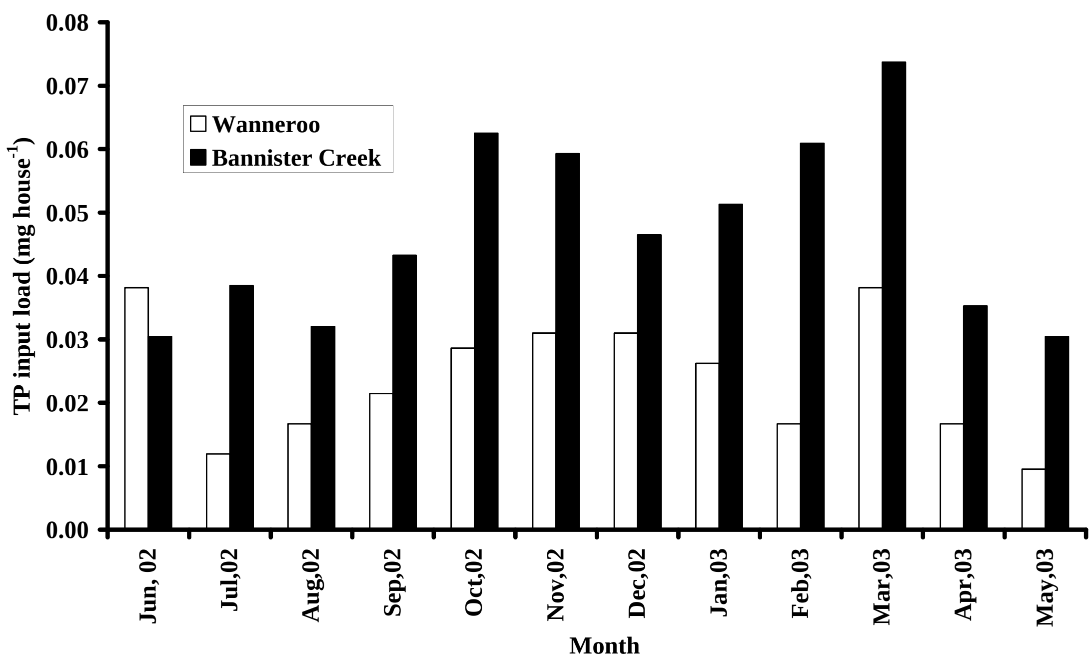


Figure 4.17 Monthly TP load per household from car washing at Bannister Creek and Wanneroo between June 2002 and May 2003.

4.8 Total Nutrient Inputs into the Catchment

The nutrient input load at Bannister Creek was lower than at Wanneroo in almost every month both in TN and TP load on a per area basis (Table 4.7).

Table 4.7 Monthly TN and TP input load per unit area into Bannister Creek and Wanneroo catchments

Month	Total TN input load into catchment ($g\ m^{-2}$)		Total TP input load into catchment ($g\ m^{-2}$)	
	Wanneroo	Bannister Creek	Wanneroo	Bannister Creek
Jun, 02	3.27	0.52	0.61	0.11
Jul,02	1.71	0.27	0.11	0.03
Aug,02	1.65	0.32	0.10	0.05
Sep,02	2.03	0.52	0.23	0.11
Oct,02	1.61	0.57	0.09	0.12
Nov,02	1.86	0.67	0.16	0.12
Dec,02	1.62	0.36	0.08	0.03
Jan,03	1.57	0.84	0.07	0.17
Feb,03	1.42	0.35	0.02	0.02
Mar,03	1.44	0.37	0.02	0.03
Apr,03	1.52	0.29	0.06	0.02
May,03	1.37	0.37	0.01	0.06
Mean ± SE	1.75 ± 0.15	0.45 ± 0.05	0.13 ± 0.05	0.07 ± 0.01
Median	1.61	0.37	0.08	0.05

Generally the TN load at both sites was highest in June 2002 and between September 2002 and January 2003 (Figure 4.18). At Bannister Creek the TN load varied from a minimum of 0.27 $g\ m^{-2}$ in July 2002 to a maximum of 0.84 $g\ m^{-2}$ in January 2003 compared to between 1.37 $g\ m^{-2}$ in May 2003 and 3.27 $g\ m^{-2}$ in June 2002 at Wanneroo.

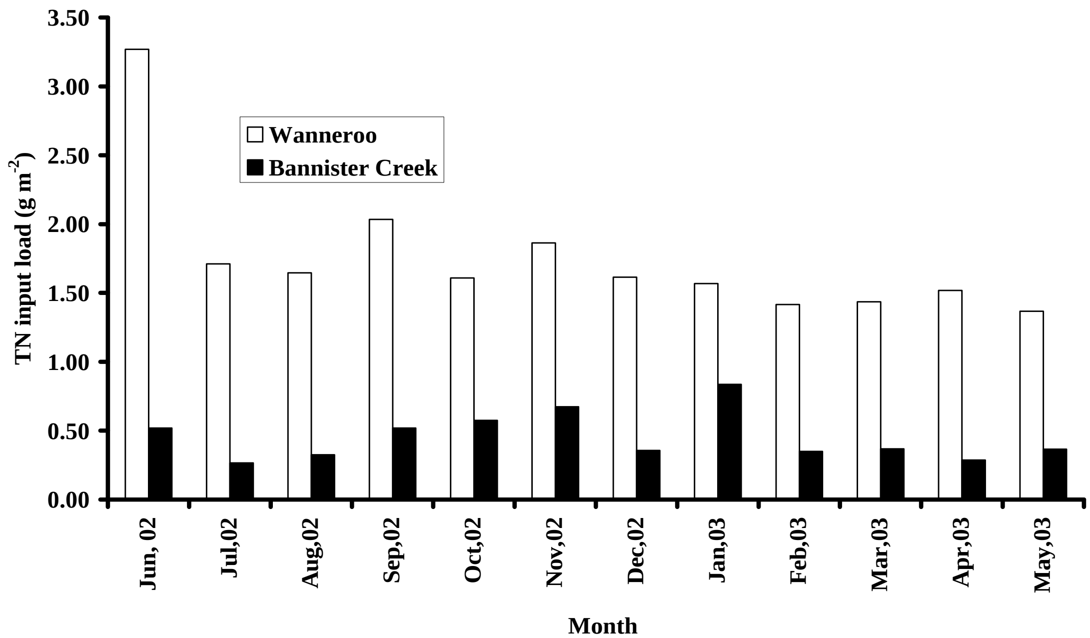


Figure 4.18 TN input load per unit area from all different input sources at Bannister Creek and Wanneroo.

The TP load followed a similar pattern to the TN load at both sites. It was above 0.07 g m^{-2} in June, September, October, November 2002 and January 2003 and not less than 0.01 g m^{-2} in July, August, December 2002, and February through to May 2003 (Figure 4.19). At Bannister Creek the TP load varied from a minimum of 0.02 g m^{-2} in February 2003 to a maximum of 0.17 g m^{-2} in January 2003 compared to between 0.01 g m^{-2} in May 2003 and 0.61 g m^{-2} in June 2002 at Wanneroo.

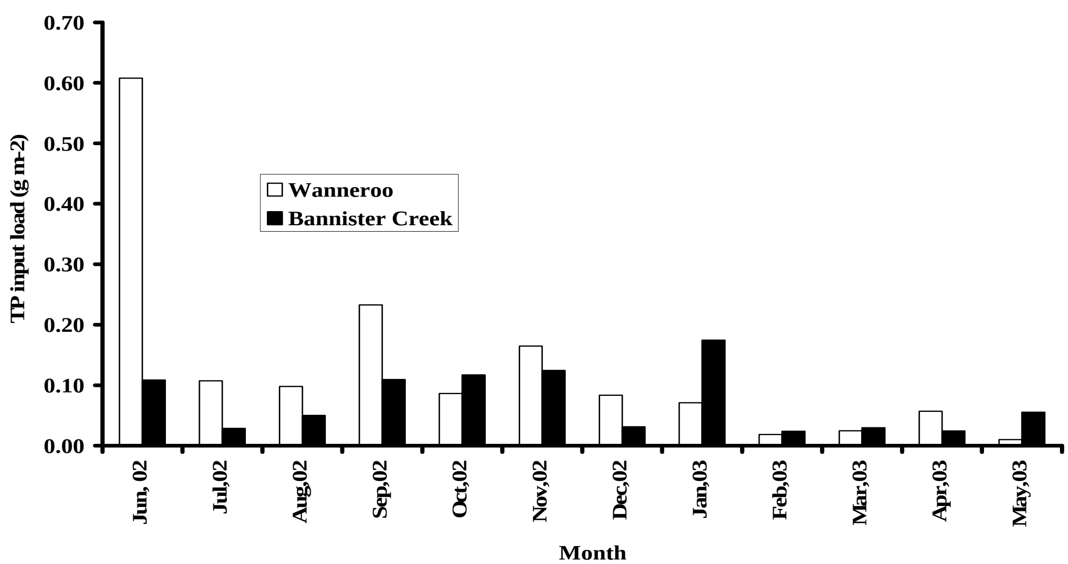


Figure 4.19 TP input load per unit area from all different input sources at Bannister Creek and Wanneroo.

The sources and quantities of TN are shown in Table 4.8 and Table 4.9 for Bannister Creek and Wanneroo respectively. The proportion of TN input load from different source components in each month is illustrated in Figure 4.20 for Bannister Creek and in Figure 4.21 for Wanneroo.

At both sites, the major nutrient input sources for TN were from fertiliser application and deposition of vehicle emissions. The minor nutrient input sources were groundwater usage on lawns, gardens, and pot plants, pet waste and rainwater. Groundwater usage on lawns, gardens, and pot plants was the more dominant of these sources at Bannister Creek but not at Wanneroo.

Table 4.8 Sources and quantity of TN load at Bannister Creek

Month	Different sources of TN input loads at Bannister Creek (kg)				
	Fertiliser	Groundwater	Rainwater	Pet	Vehicle emission
Jun, 02	330.00	2.13	41.96	19.50	126
Jul,02	88.04	0.59	31.84	19.50	126
Aug,02	153.94	5.59	19.11	19.50	126
Sep,02	353.94	11.80	8.46	19.50	126
Oct,02	382.75	33.53	12.68	19.50	126
Nov,02	397.95	124.16	5.78	19.50	126
Dec,02	86.26	124.24	1.02	19.50	126
Jan,03	546.53	143.38	0.11	19.50	126
Feb,03	60.97	140.25	2.03	19.50	126
Mar,03	81.25	128.68	12.52	19.50	126
Apr,03	64.62	62.35	12.98	19.50	126
May,03	161.19	39.28	19.78	19.50	126
Total (kg/yr)	2707.44	815.98	168.27	234.00	1512
Monthly mean ± SE	226 ± 48.17	68 ± 17.16	14.02 ± 3.66	19.50 ± 0	126 ± 0

Table 4.9 Sources and quantity of TN load at Wanneroo

Month	Different sources of TN input loads at Wanneroo study sites (kg)				
	Fertiliser	Groundwater	Rainwater	Pet	Vehicle emission
Jun, 02	378.50	0.10	7.33	7.24	252
Jul,02	71.51	0.01	6.87	7.24	252
Aug,02	61.24	0.10	4.26	7.24	252
Sep,02	138.87	0.46	3.01	7.24	252
Oct,02	53.02	2.10	3.01	7.24	252
Nov,02	101.89	5.79	0.92	7.24	252
Dec,02	50.73	8.77	0.05	7.24	252
Jan,03	42.83	7.45	0.00	7.24	252
Feb,03	11.02	8.48	0.70	7.24	252
Mar,03	13.49	8.64	1.90	7.24	252
Apr,03	34.83	3.29	2.45	7.24	252
May,03	4.39	1.25	5.07	7.24	252
Total (kg/yr)	962.33	46.45	35.56	86.87	3024
Mean ± SE	80 ± 29.31	3.87 ± 1	2.96 ± 0.72	7.24 ± 0	2.52 ± 0

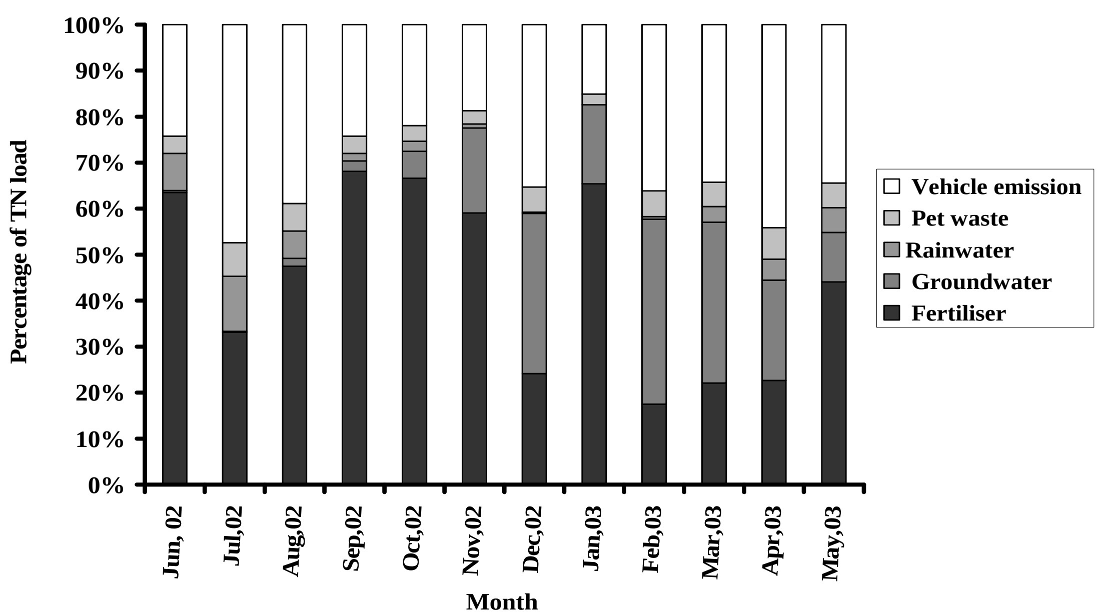


Figure 4.20 Proportion of TN from different sources in each month at Bannister Creek.

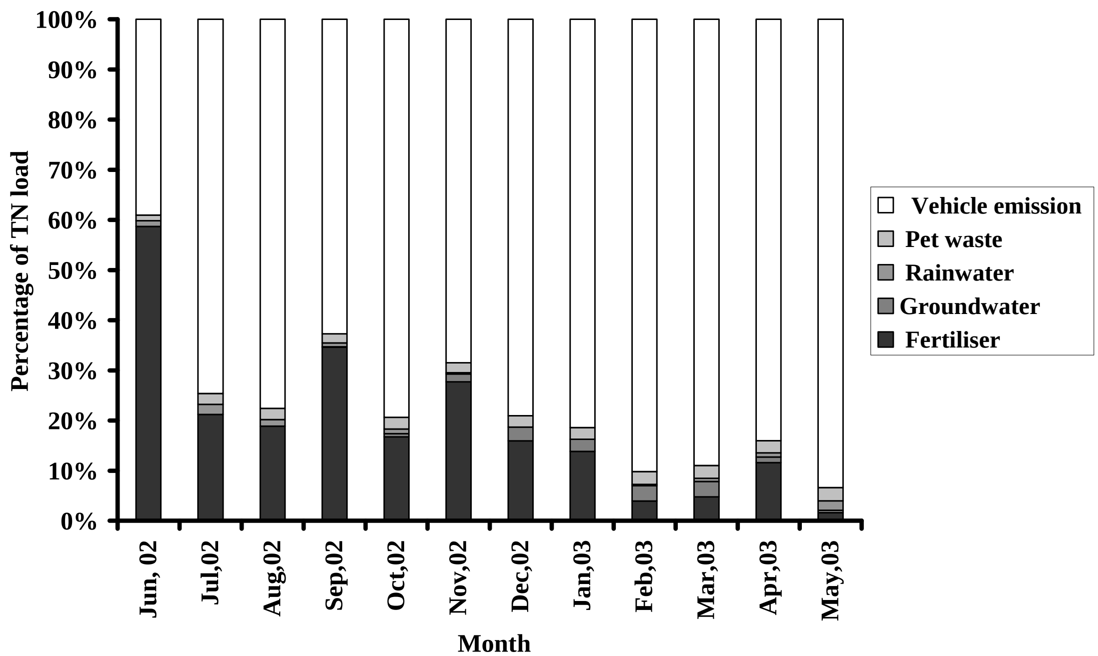


Figure 4.21 Proportion of TN from different sources in each month at Wanneroo.

The sources and quantities of TP input are shown in Table 4.10 and Table 4.11 for Bannister Creek and Wanneroo respectively. The proportion of TP input load from different sources in each month is shown in Figure 4.22 for Bannister Creek and in Figure 4.23 for Wanneroo.

The major nutrient input source for TP was from fertiliser applications at both sites. The minor nutrient input sources were from groundwater usage on lawns, gardens, and pot plants, followed by pet waste and rainwater. Lesser nutrient input sources were from car washing in both areas.

Table 4.10 Sources and quantity of TP load at Bannister Creek

Month	Different sources of TP input loads at Bannister Creek (kg)				
	Fertiliser	Groundwater	Rainwater	Pet	Carwash
Jun, 02	104.34	0.08	3.41	0.63	0.00002
Jul,02	25.18	0.02	2.59	0.63	0.00003
Aug,02	47.57	0.22	1.55	0.63	0.00003
Sep,02	107.44	0.47	0.69	0.63	0.00003
Oct,02	113.95	1.38	1.03	0.63	0.00005
Nov,02	117.90	5.52	0.47	0.63	0.00005
Dec,02	25.72	4.94	0.08	0.63	0.00004
Jan,03	168.58	5.45	0.01	0.63	0.00004
Feb,03	17.80	5.33	0.17	0.63	0.00005
Mar,03	23.58	4.50	1.02	0.63	0.00006
Apr,03	20.31	2.35	1.06	0.63	0.00003
May,03	51.46	1.68	1.61	0.63	0.00002
Total (kg/yr)	823.84	31.95	13.68	7.54	0.00045
Mean ± SE	69 ± 15	2.66 ± 1	1.14 ± 0	0.63 ± 0	0.00004 ± 0

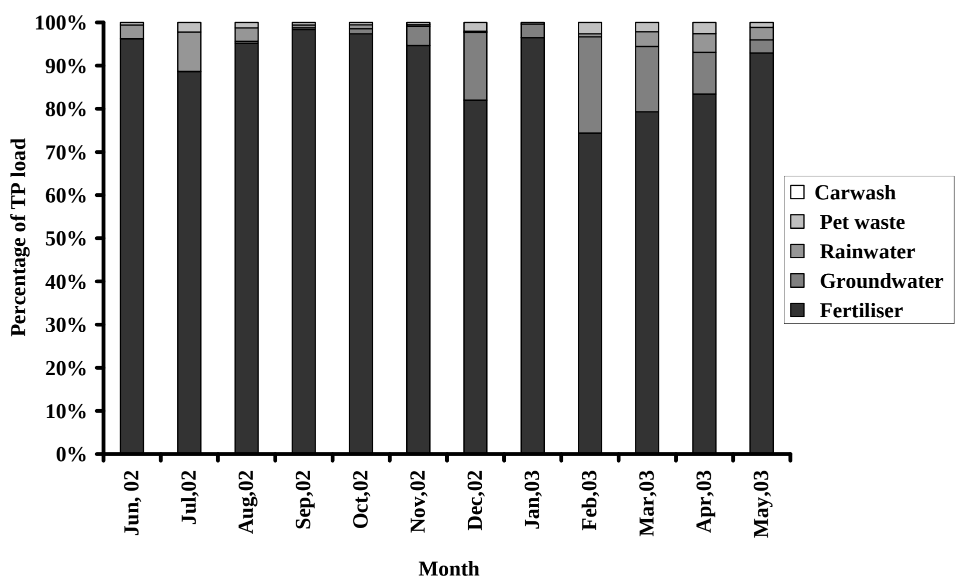


Figure 4.22 Proportion of TP from different sources in each month at Bannister creek.

Table 4.11 Sources and quantity of TP load at Wanneroo

Month	Different sources of TP input loads at Wanneroo (Kg)				
	Fertiliser	Groundwater	Rainwater	Pet	Carwash
Jun, 02	119.14	0.0016	0.596	0.23	0.000008
Jul,02	20.37	0.0002	0.559	0.23	0.000002
Aug,02	18.73	0.0016	0.347	0.23	0.000003
Sept,02	45.45	0.0069	0.244	0.23	0.000004
Oct,02	16.54	0.0315	0.245	0.23	0.000006
Nov,02	32.13	0.0965	0.075	0.23	0.000006
Dec,02	16.07	0.1404	0.004	0.23	0.000006
Jan,03	13.63	0.1590	0.000	0.23	0.000005
Feb,03	3.21	0.1425	0.057	0.23	0.000003
Mar,03	4.31	0.1685	0.154	0.23	0.000008
Apr,03	10.76	0.0349	0.199	0.23	0.000003
May,03	1.29	0.0159	0.412	0.23	0.000002
Total (kg/yr)	301.64	0.7994	2.892	2.77	0.000058
Mean ± SE	25 ± 9	0.07 ± 0.02	0.24 ± 0.06	0.23 ± 0	0.000005 ± 0

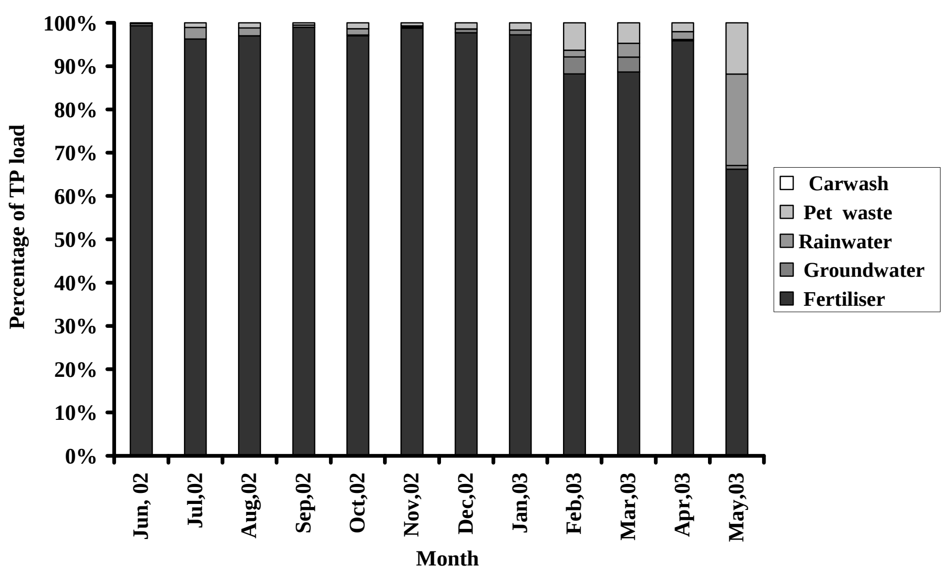


Figure 4.23 Proportion of TP from different sources at Wanneroo.

CHAPTER 5 STORMWATER OUTPUTS FROM RESIDENTIAL CATCHMENTS

This chapter introduces the characteristics of stormwater discharge from the two catchments including the physico-chemistry and the nutrient / TSS concentrations of the discharge, and loads carried by the discharge aiming to quantify the amount of nutrient output loads discharged from the household's activities in their routine life at each established residential area of the study sites. This nutrient output load will indicate the potential of the virulent of the stormwater pollution going to occur in the future if the residents are still persistent to carry on their life style in the same behavioural manner.

5.1 Discharge

The quantity of stormwater discharged from the drain at each site was dependent upon the climatic conditions, catchment characteristics, and the drainage system. At Bannister Creek, there was intrusion from groundwater whereas at Wanneroo the discharge included only stormwater.

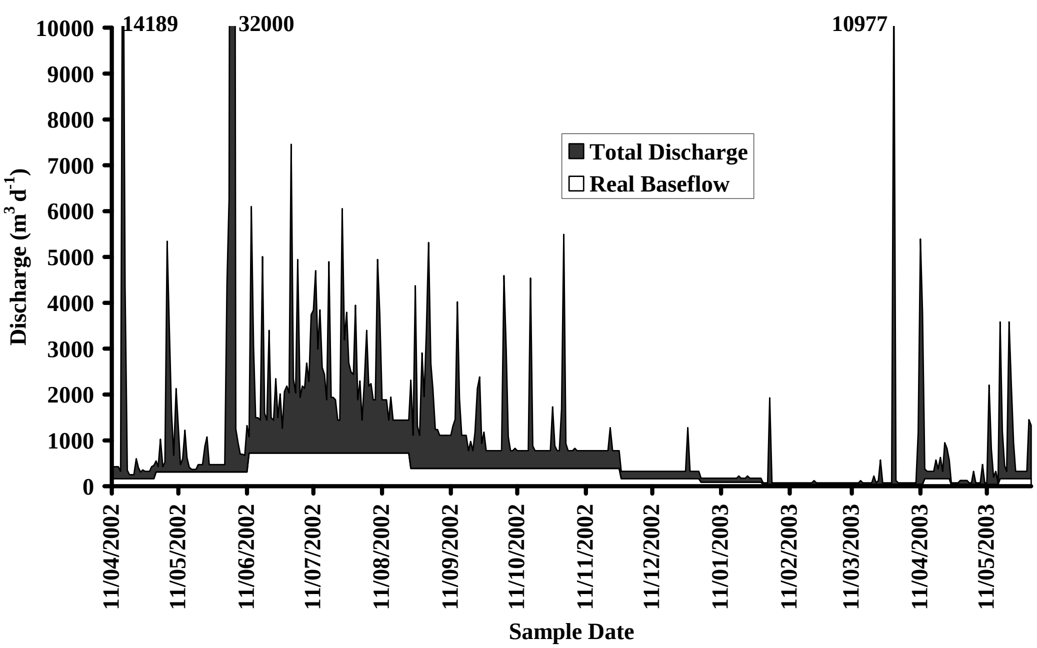


Figure 5.1 Real base flow and total discharge at Bannister Creek between April 2002 and May 2003.

At Bannister Creek (Figure 5.1), the total discharge from the drain was a combination of groundwater discharge and stormwater discharge. Any increase in discharge above base flow was considered stormwater. It takes some time for the catchment to drain after a major rain event, therefore the discharge measured after 3-4 dry days following a major rain event was considered as base flow. The period of 3-4 dry days covers the lag period between rainfall and peak flow and ensures that stormwater is excluded from base flow.

The quantity of the discharge from the drain changed with the seasons. It peaked in early April 2002 and early May 2002 at approximately 500 – 1,000 m^3 d^{-1}. This quantity decreased to around 400 –700 m^3 d^{-1} during spring and up until late October 2002, then it dropped to 36 m^3 d^{-1} in summer and 162 m^3 d^{-1} in autumn.

The peak total discharge at Bannister Creek was 33082 m^3 d^{-1} in early May 2002 with a yearly mean (± se) of 957 ± 20.49 m^3 d^{-1}. The real base flow followed a similar pattern. The real base flow was low; around 36 m^3 d^{-1} in summer from December 2002 to April 2003. Then it gradually increased from April 2002 to a high level in early winter from June to August 2002 with a maximal value of 721 m^3 d^{-1} and gradually dropped to the low level again with a mean (± se) of 293 ± 11.58 m^3 d^{-1}.

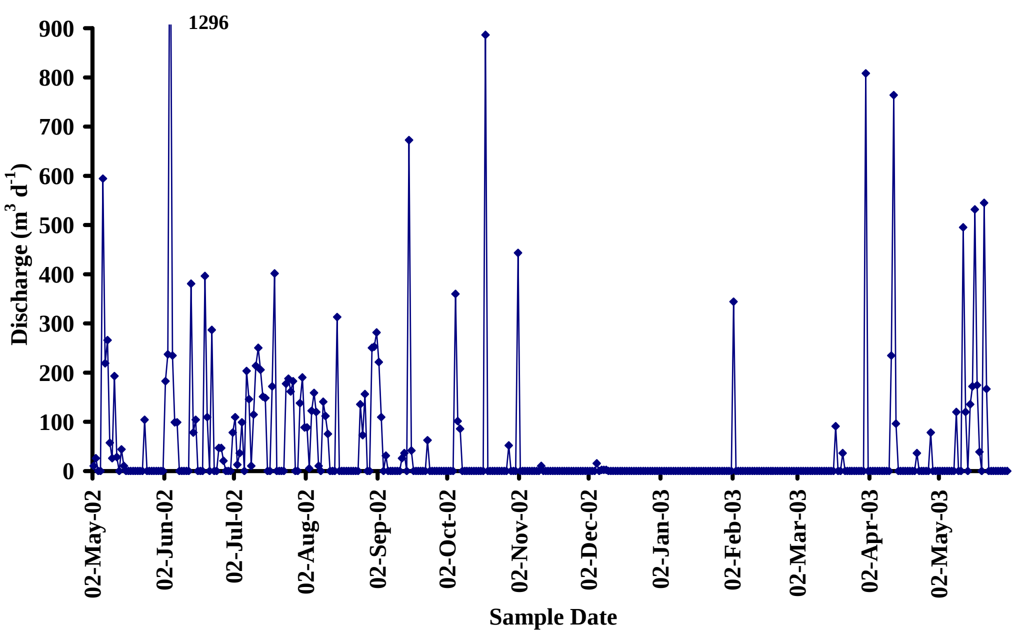


Figure 5.2 Quantity of stormwater discharge at the Wanneroo site between April 2002 and May 2003.

At Wanneroo, the quantity of stormwater discharged from the drain was due entirely to rainfall in the catchment. Discharge (Figure 5.2) was high from May 2002 to November 2002 with a maximum of 1296 m^3 d^{-1} on 4 June 2002 and low in the late spring and summer around 3 m^3 d^{-1} with a mean (± se) of 184 ± 20.49 m^3 d^{-1}.

At Bannister Creek, the quantity of total discharge (Figure 5.3) from the drain over the studied 24 hour periods varied seasonally from a minimum of 0.15 m^3 hr^{-1} on 24 May 2003 to a maximum of 3 m^3 hr^{-1} on 24 August 2002. Total discharge was very consistent over the 24 hour periods in each season, if there was no rain falling in the catchment. On 24 August 2002, there was a rainfall event (5 mm) at 16.00 hrs that appears to be responsible for the increase in the total discharge from 3 m^3 hr^{-1} to 21 m^3 hr^{-1}; however, four hours later the total discharge had returned to pre-rainfall levels. At Wanneroo, no flow was recorded during the 24 hour periods sampled.

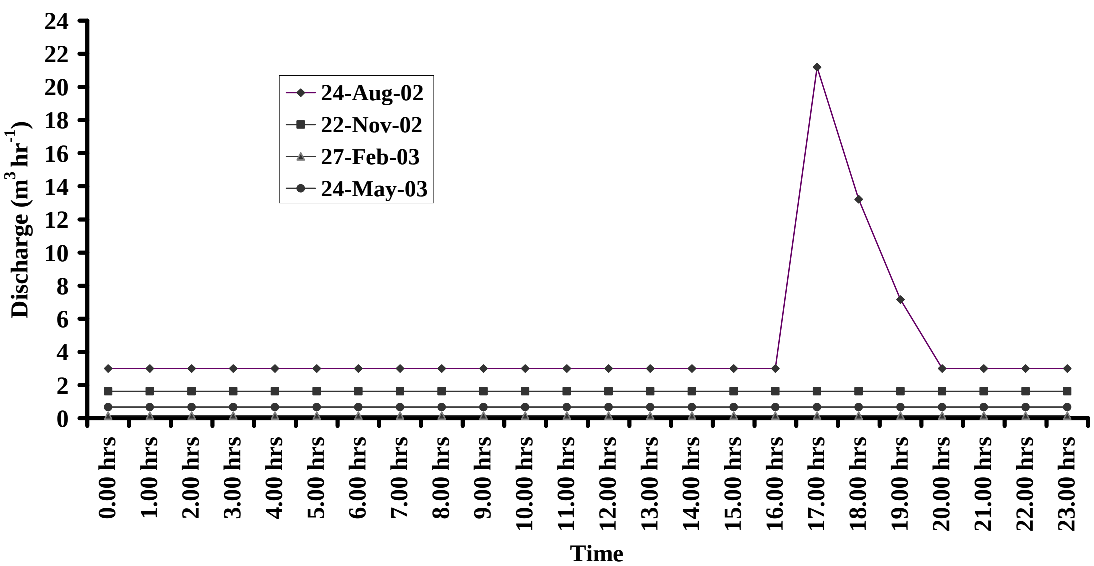


Figure 5.3 Discharge over a 24 hour period, sampled once in each season in the Bannister Creek drain between August 2002 and May 2003.

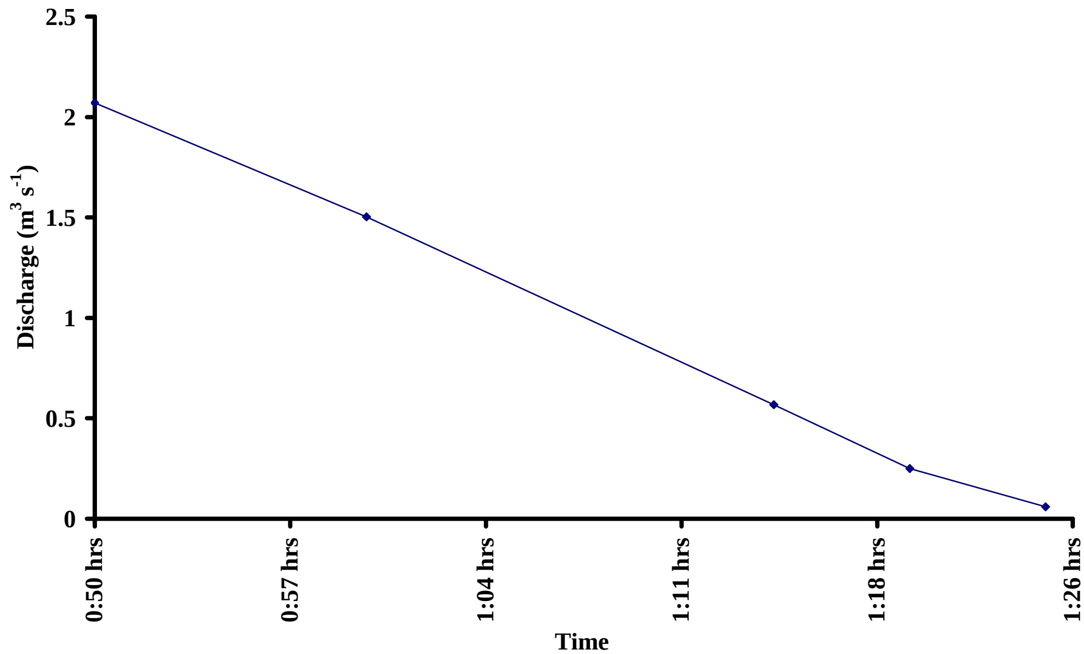
The hydrographs of the major storm events sampled at both sites captured only the falling limb of the flow. The rising limb of the flow in each major storm event was missed due to the difficulty in getting to the sites prior to the storm event.

At Bannister Creek, the major storm events on 9 August 2002 and 14 September 2002 were triggered by rainfall events of similar magnitude (about 12 mm or equivalent to ARI = 1). On 9 August 2002 the total discharge dropped from 2.07 $m^3 s^{-1}$ to the base flow at 0.06 $m^3 s^{-1}$ over 35 minutes (Figure 5.4a). On 14 September 2002, the total discharge declined from 0.56 $m^3 s^{-1}$ to base flow of 0.059 $m^3 s^{-1}$ over 20 minutes (Figure 5.4b). Although the rainfall events on 9 August 2002 and 14 September 2002 were similar in magnitude, there was a huge difference in response, such as the maximum discharge mentioned above. This different response was caused by differences in climatic conditions i.e. antecedent time, rainfall intensity, and duration. In this case it was found that the antecedent time (3 days) before the 9 August 2002 storm event was longer than the antecedent time (0 days) on 14 September 2002.

At Wanneroo, a storm event was captured on 11 April 2003 following 29 mm of rain or equivalent to ARI = 2-5 (Figure 5.5). This resulted in discharge exceeding 0.015 $m^3 s^{-1}$, and then declining to 0.002 $m^3 s^{-1}$ over 22 minutes. Then the discharge or flow rate was constant at 0.002 $m^3 s^{-1}$ for a certain period. Subsequently, the rate increased rapidly to 0.015 $m^3 s^{-1}$ at 12.00 hrs and then 0.031 $m^3 s^{-1}$ at 12.02 hrs.

Data collected during the period the depth sensor was installed showed that the quantity of estimated runoff was less than the true discharge as measured by the depth sensor. A reduction of 42,473 m^3 (45.6%) was underestimated during the period of installation (Figure 5.6). This suggested that the estimated amount of nitrogen and phosphorus discharged from the residential catchment would probably be substantially higher than the presented values.

a) 9 August 2002



b) 14 September 2002

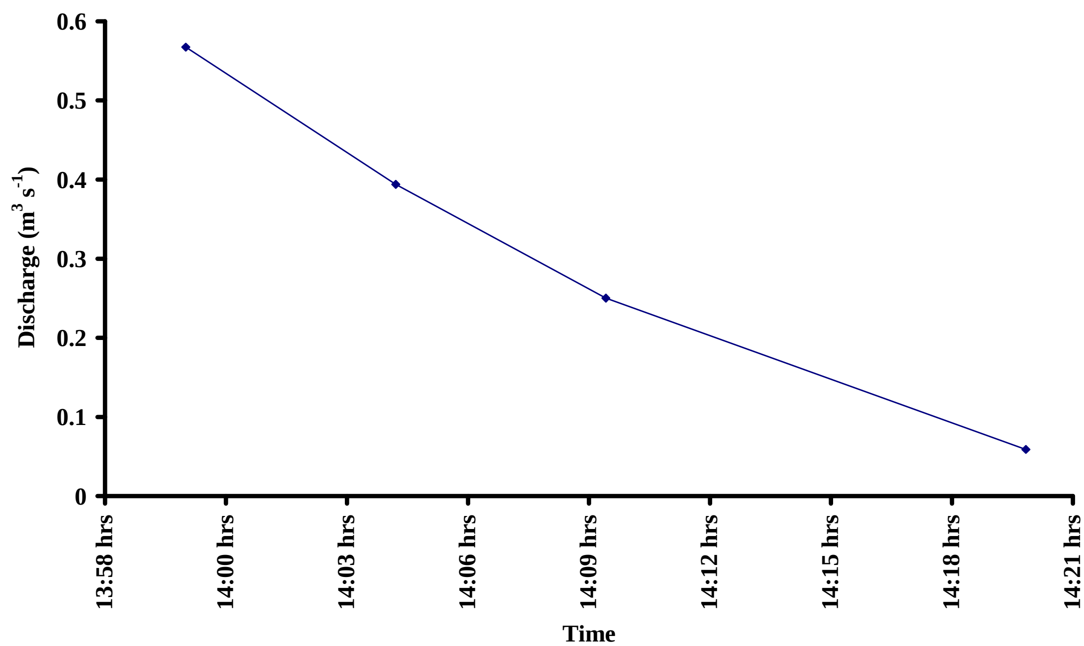


Figure 5.4 Time series of discharge in major storm event captured at Bannister Creek on a) 9 August 2002, and b) 14 September 2002.

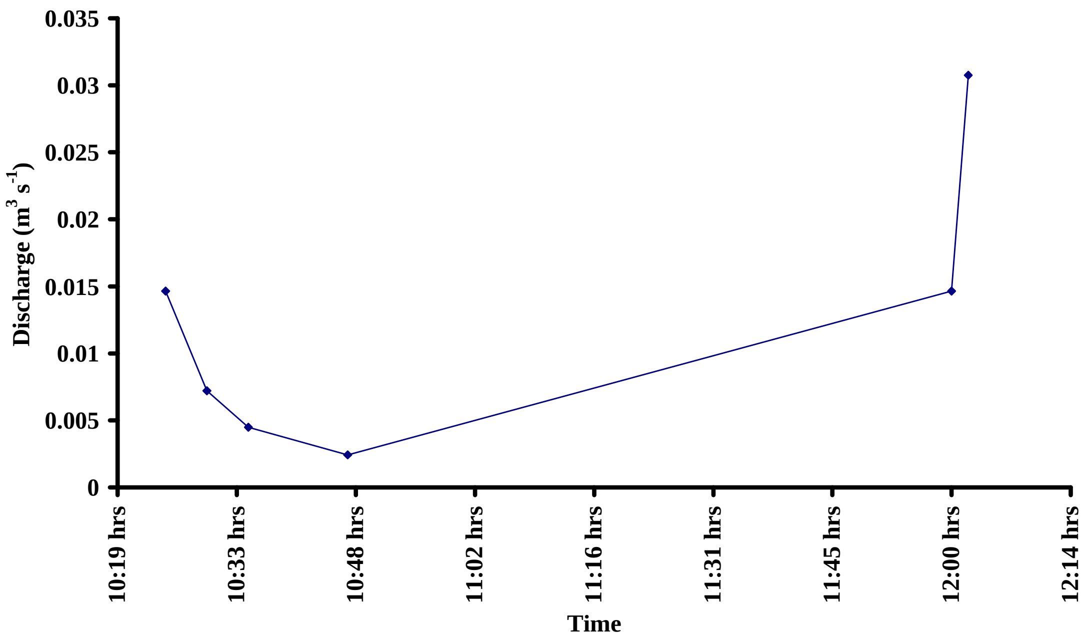


Figure 5.5 Time series of discharge during a major storm event captured at Wanneroo on 11 April 2003.

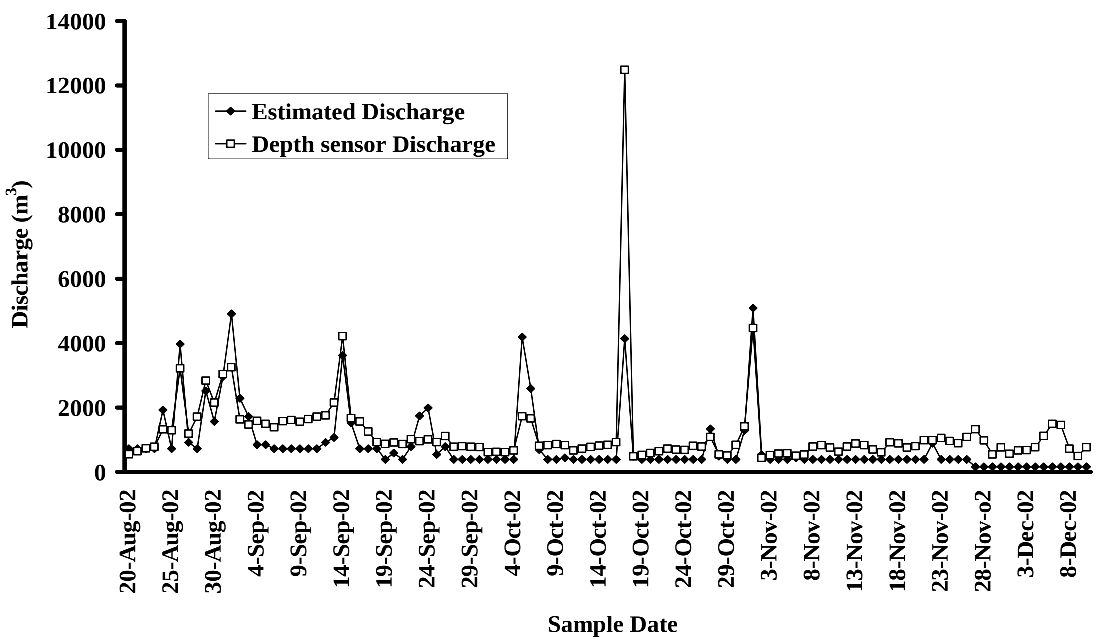


Figure 5.6 The variation of discharge between depth sensor and measuring depth at Bannister Creek during installation period (20 August - 11 December 2002).

5.2 Physico-chemical Parameters of Water Samples

5.2.1 Routine Samples

The physico-chemical parameters of routine samples at the Bannister Creek and Wanneroo sites are shown in Table 5.1.

Table 5.1 Physico-chemical parameters of routine samples at Bannister Creek (n = 171) and Wanneroo (n = 27)

Parameter	pH	Conductivity	Temperature	Turbidity	Dissolved Oxygen		Redox Potential
		$\mu S\ cm^{-1}$	^oC	NTU	$mg\ L^{-1}$	% Saturation	mV
BANNISTER CREEK							
Range	6.96-8.70	269-2446	17.9-26.2	0-35.8	3.8-11.3	46-121	-46-135
Mean ± SE	7.76 ± 0.03	945 ± 20.25	21.7 ± 0.16	4.1 ± 0.34	7.1 ± 0.15	81 ± 1.53	49 ± 3.02
Median	7.77	929	21.8	3.0	7.9	88	51
WANNEROO							
Range	7.61-8.73	38-346	14.3-26.3	0-29	5.2-10.7	51-105	26-113
Mean ± SE	8.02 ± 0.06	135 ± 13.21	17.5 ± 0.46	0.4 ± 0.15	9.3 ± 0.25	93 ± 3.70	43 ± 8.45
Median	7.92	131	16.8	0.0	9.5	99	46

In general, pH values at both sites were between 7 and 8. However, on mean, the water samples from Wanneroo were slightly more alkaline than those from Bannister Creek (Figure 5.7). At Bannister Creek, the pH of routine samples ranged from a minimum of 6.96 on 6 June 2002 to a maximum of 8.70 on 6 March 2003 with a mean (± se) of 7.76 ± 0.03. The pH at Bannister Creek showed significant ($P < 0.05$) but weak ($r = 0.28$) correlation to discharge. At Wanneroo, the pH of routine samples had a mean (± se) of 8.02 ± 0.06 ranging from a minimum of 7.61 on 24 July 2002 to a maximum of 8.73 on 3 September 2002. At Wanneroo, pH was not correlated to discharge ($P>0.05$, $r = 0.19$).

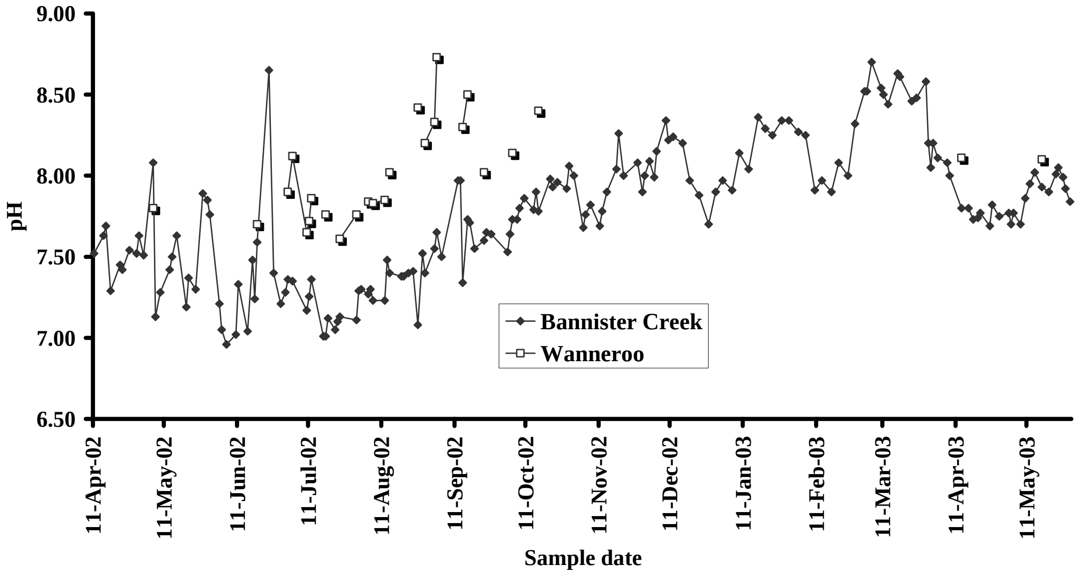


Figure 5.7 pH measured during the regular sampling program at Bannister Creek and Wanneroo (April 2002 to May 2003).

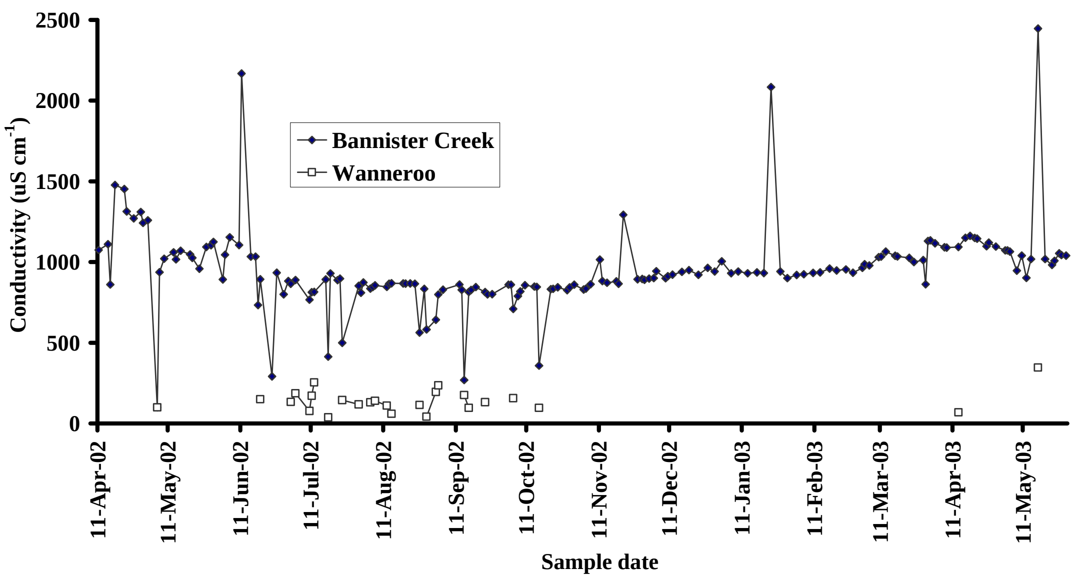


Figure 5.8 Conductivity measured during the regular sampling program at Bannister Creek and Wanneroo (April 2002 to May 2003).

The conductivity of routine samples at Bannister Creek was high, with a mean (± se) of 945 ± 20.25 μS cm^{-1} compared to Wanneroo which had a very low mean (± se) of 135 ± 13.21 μS cm^{-1} (Figure 5.8). At Bannister Creek, the conductivity of routine samples was variable ranging from a minimum of 269 μS cm^{-1} on 14 September 2002 to a maximum of 2,446 μS cm^{-1} on 17 May 2003. The conductivity of routine samples at Bannister Creek was not correlated with discharge (P > 0.05; r = 0.13). At Bannister Creek there was a slight seasonal rise in conductivity over the warmer months and a decline in winter. At Wanneroo, the conductivity of routine samples ranged from a minimum of 38 μS cm^{-1} on 18 July 2002 to a maximum of 346 μS cm^{-1} on 17 May 2002 and showed no correlation with discharge (P > 0.05; r = 0.22).

The temperature of routine samples at both sites varied seasonally between 15 ºC and 26 ºC. However, on mean, Bannister Creek routine samples were warmer than Wanneroo routine samples (Figure 5.9). At Bannister Creek, the temperature of routine samples varied from a minimum of 17.9 ºC on 14 September 2002 to a maximum of 26.2 ºC on 10 March 2003 with a mean (± se) of 21.7 ± 0.16 ºC. The temperature at Bannister Creek showed a significant correlation with discharge with a weak relationship (P < 0.001; r = 0.26). At Bannister Creek there was a seasonal rise in water temperature during the summer months and a decline in winter. At Wanneroo, the temperature of routine samples ranged from a minimum of 14.3 ºC on 16 September 2002 to a maximum of 26.3 ºC on 13 April 2003 with a mean of 17.5 ± 0.46 ºC and showed no correlation with discharge (P > 0.05; r = 0.06).

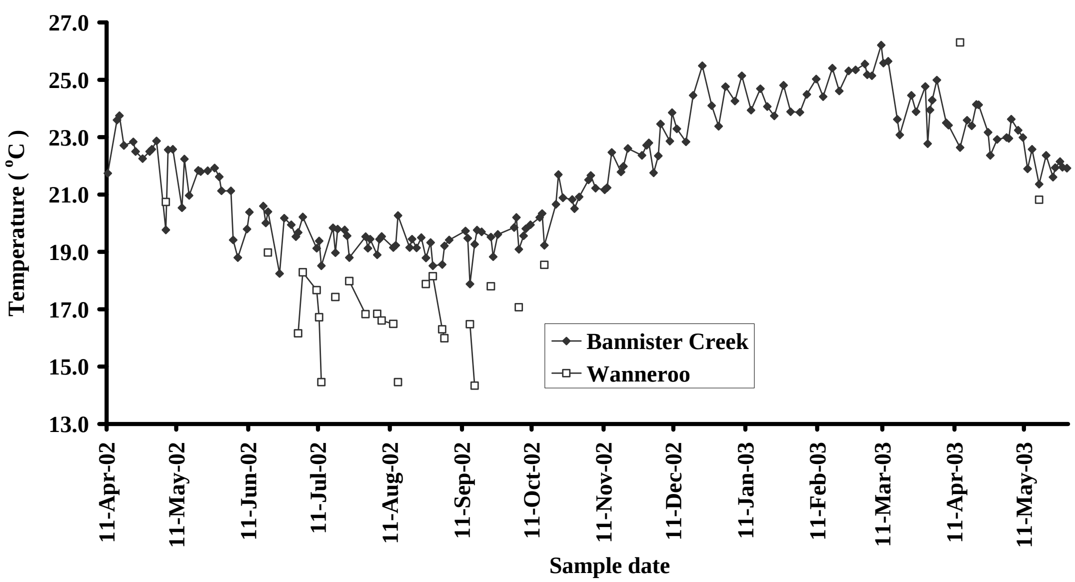


Figure 5.9 Temperature measured during the regular sampling program at Bannister Creek and Wanneroo (April 2002 to May 2003).

The turbidity of routine samples varied seasonally. It was high in summer and autumn but was low in winter (Figure 5.10). At Bannister Creek, the turbidity of routine samples ranged from a minimum of 0 NTU on a number of occasions between April and July to a maximum of 35.8 NTU on 24 June 2002 with a mean (± se) of 4.1 ± 0.34 NTU and showed no correlation with discharge ($P > 0.05$; $r = 0.10$). At Wanneroo, the turbidity of routine samples was generally consistent and very low <1 NTU and showed no correlation with discharge ($P > 0.05$; $r = 0.06$).

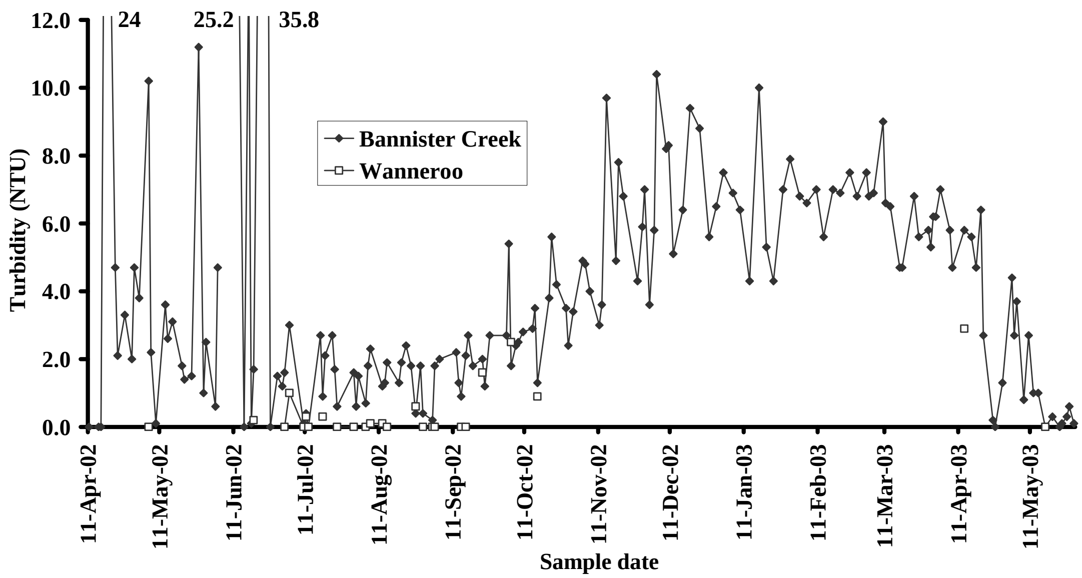
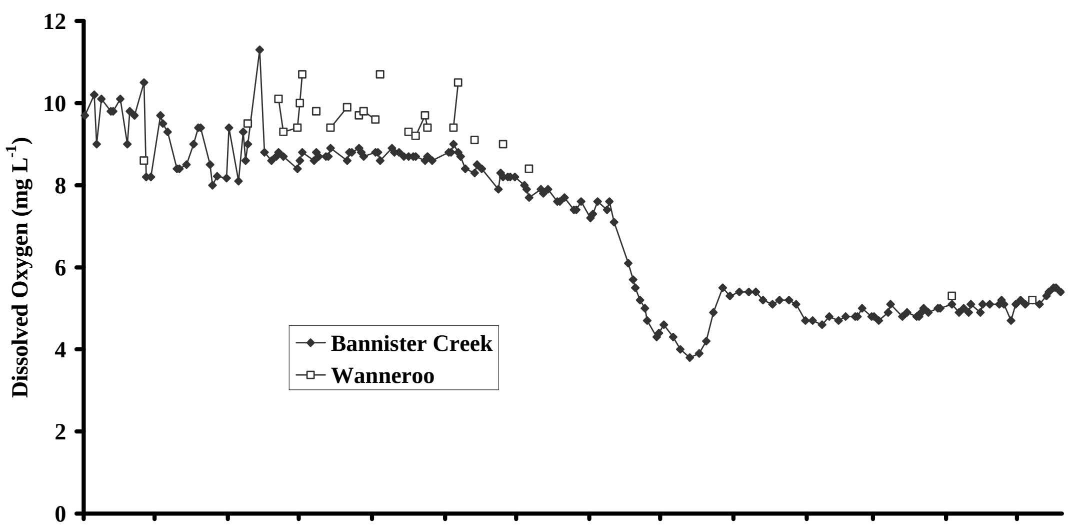


Figure 5.10 Turbidity measured during the regular sampling program at Bannister Creek and Wanneroo (April 2002 to May 2003).

The dissolved oxygen (DO) concentration and percentage saturation of routine samples followed a similar pattern at both sites (Figure 5.11). Dissolved oxygen was high in the wet season, from April 2002 to November 2002, but fell during the period December 2002 to May 2003. At Bannister Creek, the dissolved oxygen concentration of routine samples was variable, ranging from a minimum of 3.8 mg L^{-1} (46%) on 23 December 2002 to a maximum of 11.3 mg L^{-1} (121 %) on 24 June 2002 with a mean (± se) of 7.1 ± 0.15 mg L^{-1} or 81 ± 1.53% respectively and was significantly correlated ($P < 0.05$) to discharge with a weak relationship ($r = 0.20$). At Wanneroo, the DO concentration of routine samples were variable, ranging from a minimum of 5.2 mg L^{-1} (58%) on 17 May 2003 to a maximum of 10.7 mg L^{-1} (58%) on 12 July and 14 August 2002 with a mean (± se) of 9.3 ± 0.25 mg L^{-1}

or 93 ± 3.70% and showed no correlation with discharge ($P > 0.05$; $r = 0.04$, 0.30 for concentration and percentage saturation respectively).

a) Concentration



b) Percentage saturation

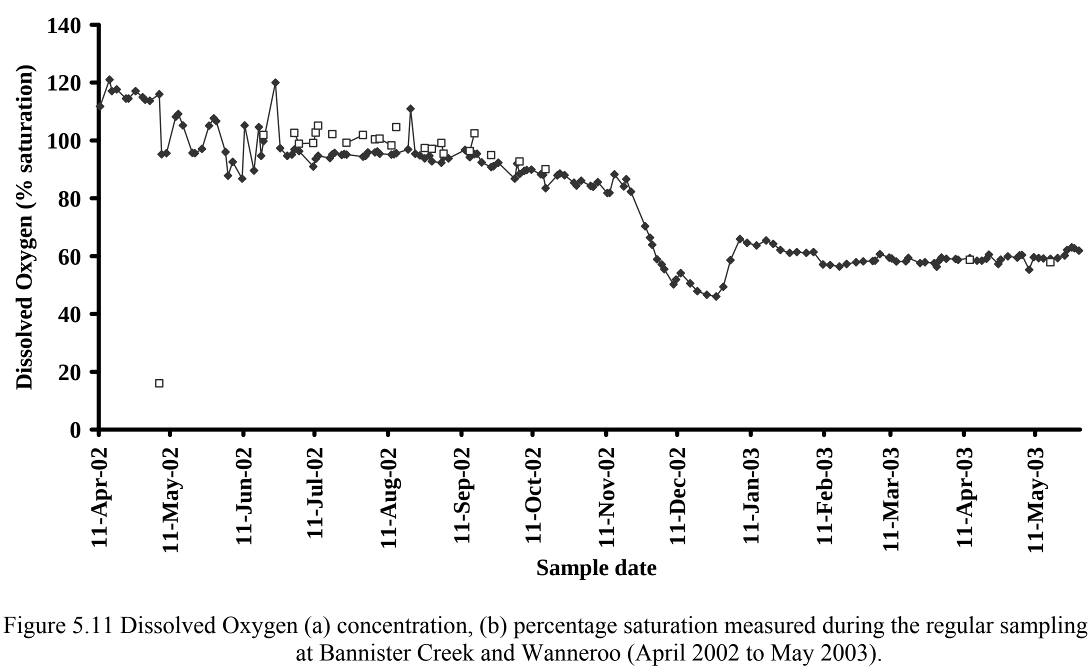


Figure 5.11 Dissolved Oxygen (a) concentration, (b) percentage saturation measured during the regular sampling program at Bannister Creek and Wanneroo (April 2002 to May 2003).

The redox potential of routine samples at both sites was rather low and variable from early July 2002 to May 2003 with a mean of 46 mV (Figure 5.12). At Bannister Creek, the redox potential of routine samples ranged from a minimum of -46 mV on 23 March 2003 to a maximum of 135 mV on 12 May 2003 with a mean (± se) of 49 ± 3.02 mV and showed no correlation with discharge ($P > 0.05$; $r = 0.01$). At Wanneroo, the redox potential of routine samples ranged from a minimum of 26 mV on 29 August 2002 to a maximum of 113 mV on 17 May 2003 with a mean of 43 ± 8.45 mV and also showed no correlation with discharge ($P > 0.05$; $r = 0.39$).

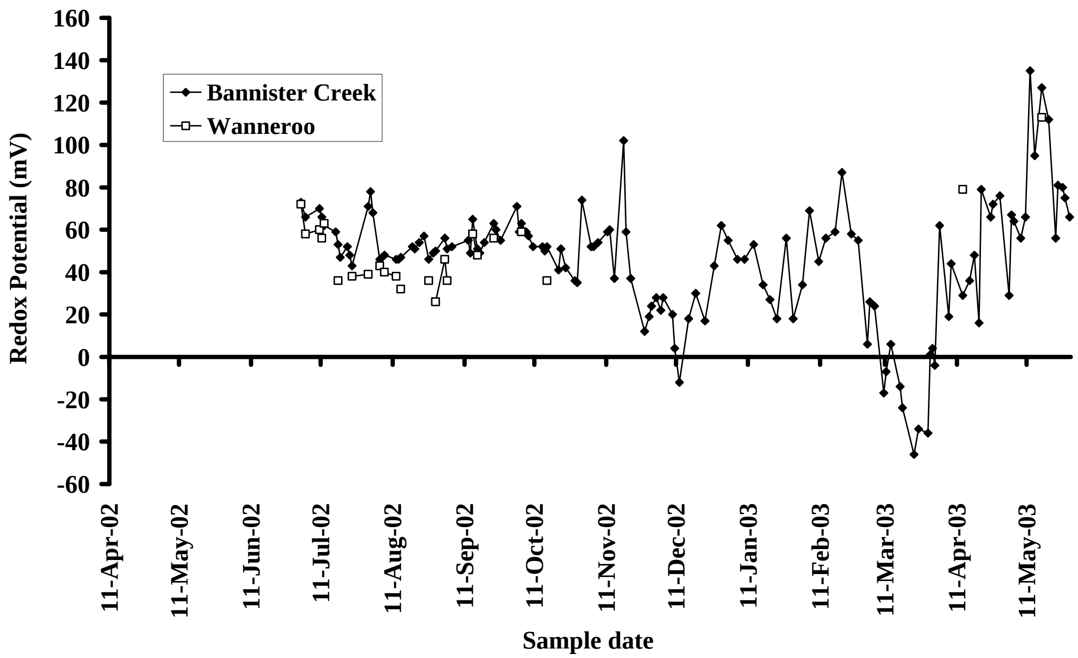


Figure 5.12 Redox potential measured during the regular sampling program at Bannister Creek and Wanneroo (April 2002 to May 2003).

5.2.2 Hourly Water Samples Taken over 24 Hours

The physico-chemical parameters over the 24 hour sample periods at Bannister Creek and Wanneroo are shown in Table 5.2. At Wanneroo, the samples were collected only on one occasion for 7 hours (11.00 hrs – 18.00 hrs), as this was the only 24 hour sampling period where there was water flowing in the drain.

Table 5.2 Physico-chemical parameters over the 24 hour sample periods at Bannister Creek and Wanneroo

Parameter	pH	Conductivity	Temperature	Turbidity	Dissolved Oxygen		Redox Potential
		µS cm^{-1}	^{o}C	NTU	mg L^{-1}	% Saturation	mV
BANNISTER CREEK 24 AUGUST 2002 (Flow = 0.72 m s^{-1})							
Range	7.4-7.88	381-866	18.44-19.63	0-93.5	8.6-8.7	91.80-95.10	45-63
Mean ± SE	7.67 ± 0.03	765.38 ± 29.77	19.03 ± 0.07	4.33 ± 3.88	8.65 ± 0.01	93.49 ± 0.21	54.33 ± 1.15
Median	7.69	831	19.0	0.4	8.7	93	55.5
BANNISTER CREEK 22 NOVEMBER 2002 (Flow = 0.60 m s^{-1})							
Range	7.96-8.49	852-900	21.41-22.54	1.60-8.80	6.90-7.20	78.90-83.20	-14-19
Mean ± SE	8.24 ± 0.03	876.46 ± 1.92	21.86 ± 0.06	3.45 ± 0.35	7.05 ± 0.02	80.42 ± 0.29	4.17 ± 1.59
Median	8.19	879	21.8	3.1	7.0	80	4
BANNISTER CREEK 27 FEBRUARY 2003 (Flow = 0.29 m s^{-1})							
Range	8.32-8.77	934-967	22.34-25.35	2.30-6.80	4.80-5.0	57.10-59.80	14-55
Mean ± SE	8.60 ± 0.02	959.92 ± 1.57	23.65 ± 0.20	4.78 ± 0.30	4.92 ± 0.02	58.07 ± 0.16	28.67 ± 1.80
Median	8.59	964	23.5	4.8	4.9	58	28
BANNISTER CREEK 24 MAY 2003 (Flow = 0.46 m s^{-1})							
Range	8.05-8.65	988-1028	20.66-22.19	0-0.10	5.4-5.5	61.20-62.70	36-81
Mean ± SE	8.50 ± 0.03	1014.50 ± 1.63	21.38 ± 0.10	0.0	5.46 ± 0.01	61.93 ± 0.08	65.54 ± 2.57
Median	8.54	1015	21.4	0.0	5.5	62	71
WANNEROO 1 SEPTEMBER 2002							
Range	7.8-8.04	97-366	12.09-16.71	0.0	9.50-10.80	96.60-100.40	55-65
Mean ± SE	7.95 ± 0.03	155.60 ± 44.48	15.31 ± 0.69	0.0	9.84 ± 0.11	98.04 ± 0.54	61.80 ± 1.47
Median	7.98	105	15.8	0.0	9.7	98	63

The pH of the water sample periods over the 24 hours at both sites was very consistent varying by less than 1 pH unit on each occasion (Figure 5.13). At Bannister Creek there was an unusual dip in pH on all four occasions of > 0.5 pH units between 13 hrs and 16 hrs. This was not found at Wanneroo.

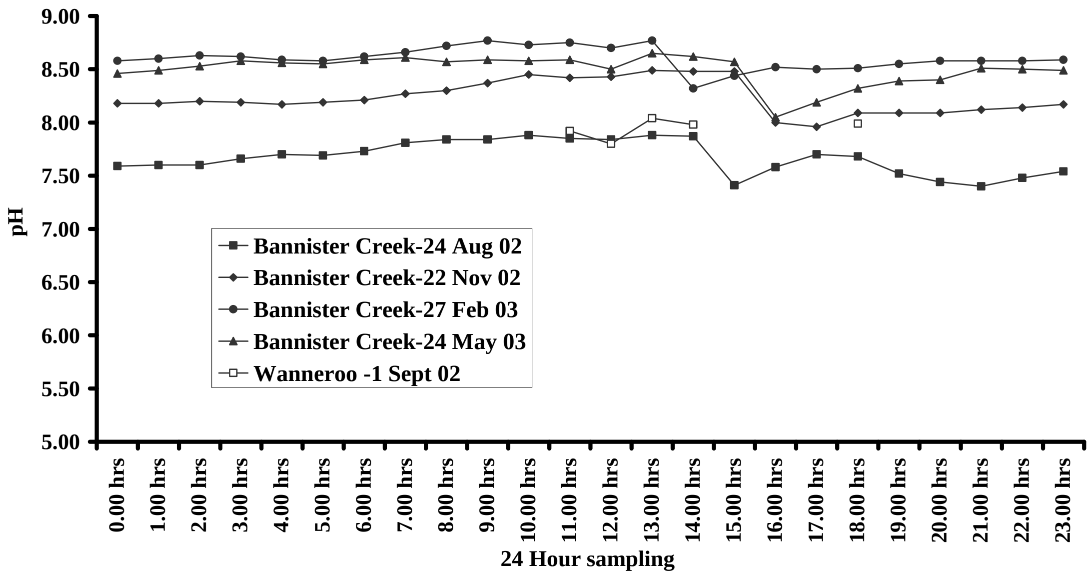


Figure 5.13 pH measured in the hourly water samples taken over 24 hours from the drains at Bannister Creek in each season and at Wanneroo (in September 2002) between April 2002 and May 2003.

During the 24 hour sampling period in Bannister Creek over each season, conductivities changed very little, ranging between about 800 and 1,000 μS cm^{-1}. The exception was on the 24 August 2002 when the conductivity dropped by approximately 400 μS cm^{-1} before rising gradually during the final five hours of sampling (16.00 -20.00 hrs) (Figure 5.14). This was probably due to rainfall at the sampling site from 16.00 hrs to 20.00 hrs. This resulted in a significant increase in discharge (Figure 5.3) and probably reduction of conductivity in the discharge by dilution. At Wanneroo, the conductivity of the hourly water samples taken over 24 hours was low, between 11 hrs and 14 hrs at 97 μS cm^{-1}, but rose to 366 μS cm^{-1} at 18.00 hrs. The cause of the rise is unknown (Figure 5.14).

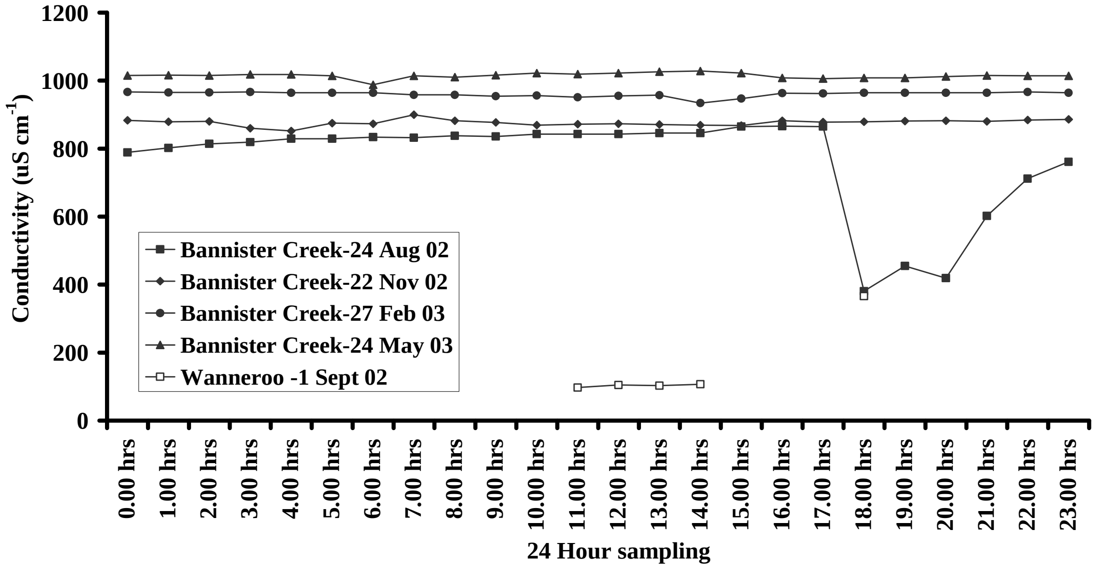


Figure 5.14 Conductivity measured in the hourly water samples taken over 24 hours from the drains at Bannister Creek in each season and at Wanneroo (in September 2002) between April 2002 and May 2003.

The water temperature over the 24 hours on each occasion at Bannister Creek showed a slight increase during the afternoon (especially in the summer) but overall varied by < 2 ^{o}C (Figure 5.15). At Wanneroo the temperature of the water samples was slightly lower than those at Bannister Creek (around 3-8 ^{o}C lower) but one sample dropped to 12 ^{o}C. The cause of the drop is unknown, but corresponded with the rise in conductivity mentioned above.

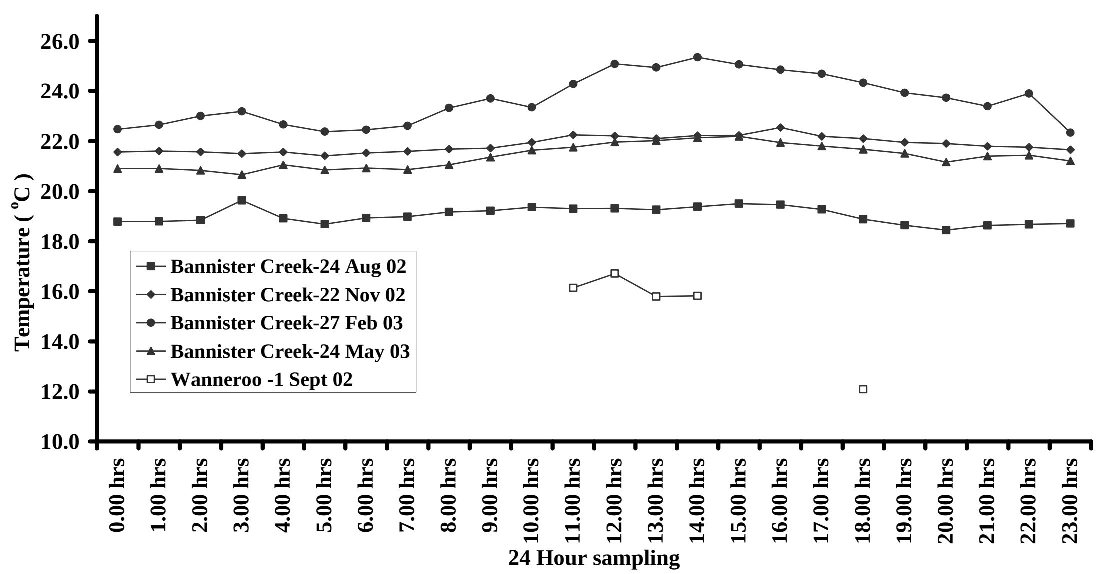


Figure 5.15 Temperature measured in the hourly water samples taken over 24 hours from the drains at Bannister Creek in each season and at Wanneroo (in September 2002) between April 2002 and May 2003.

The turbidity of the water samples over the 24 hour sample period at Wanneroo was zero. In contrast, the turbidity at Bannister Creek varied over the 24 hour period and between seasons (Figure 5.16). On 24 May 2003 turbidity was < 0.1 NTU and it was < 2 NTU on the 24 August 2002 except for a peak at 93.5 NTU which occurred following a rainfall event (detailed in section 5.2.2 of conductivity). On the 22 November 2002 and 27 February 2003 the turbidity ranged between 2 and 9 NTU, generally being higher between 8 hrs and 18.00 hrs.

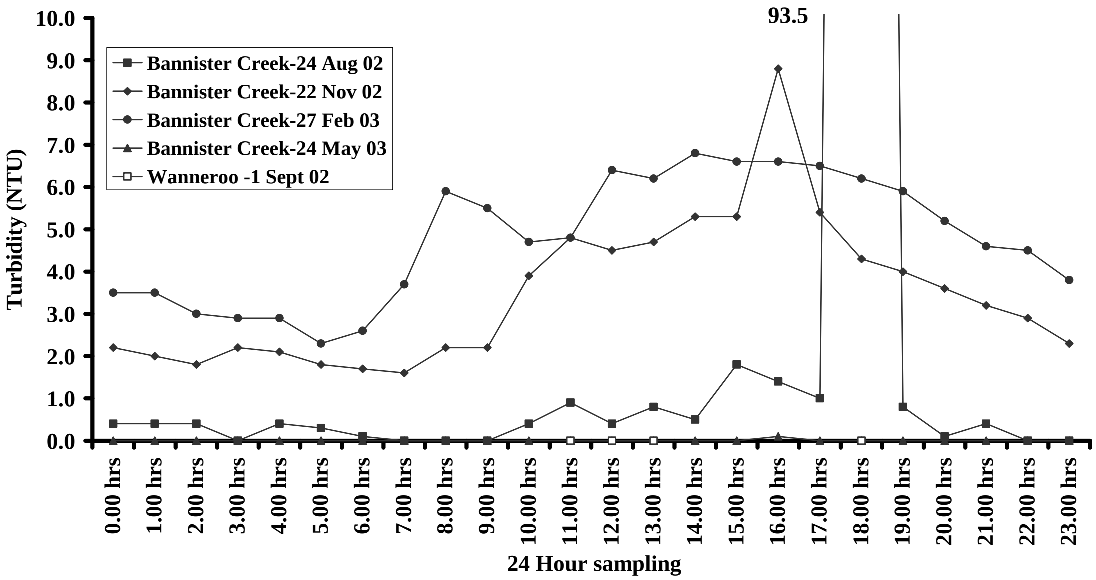
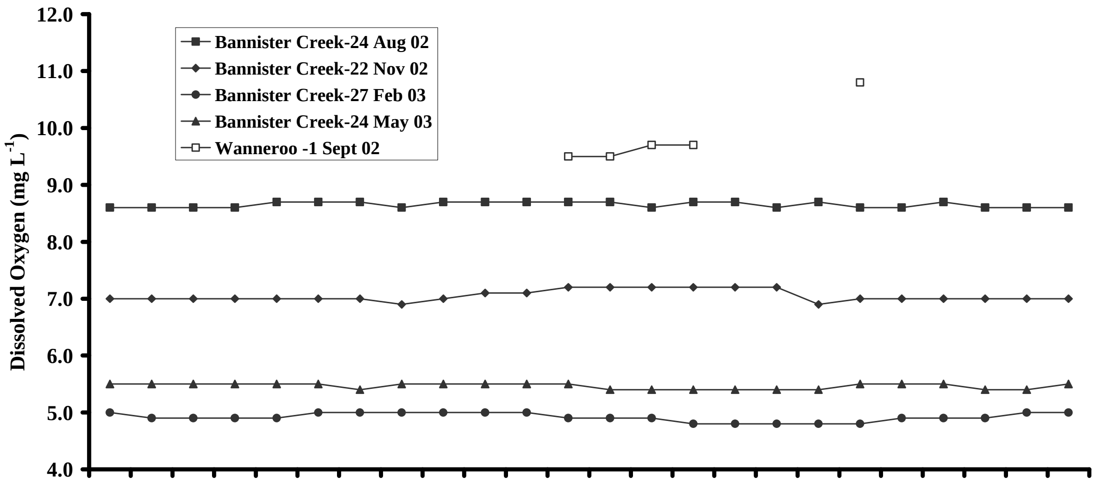


Figure 5.16 Turbidity measured in the hourly water samples taken over 24 hours from the drains at Bannister Creek in each season and at Wanneroo (in September 2002) between April 2002 and May 2003.

The concentration of dissolved oxygen over the 24 hour periods at both sites changed little but varied between seasons at Bannister Creek from a minimum of 5 mg L^{-1} on 27 February 2003 to a maximum of 8.7 mg L^{-1} on 24 August 2002 (Figure 5.17a). At Wanneroo, the dissolved oxygen concentration on 1 September 2002 was slightly higher than that recorded at Bannister Creek, reaching a maximum of 10.8 mg L^{-1} (close to 100% saturation). All the 24 hour sample sets at Bannister Creek showed low dissolved oxygen saturations, close to 60% in February and May 2003 and 80% in November 2002 and 90% in August 2002 (Figure 5.17b). No diurnal pattern was evident at either site indicating low primary productivity in the waters.

a) Concentration



b) Percentage saturation

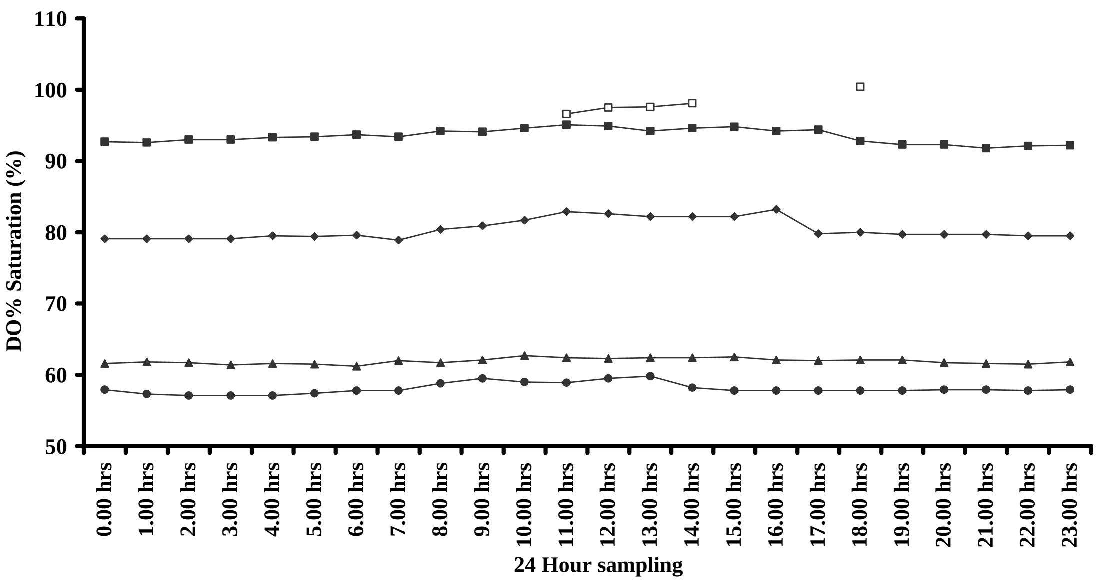


Figure 5.17 Dissolved oxygen (a) concentration, (b) percentage saturation measured in the hourly water samples taken over 24 hours from the drains at Bannister Creek in each season and at Wanneroo (in September 2002) between April 2002 and May 2003.

The redox potential over the 24 hour periods at both sites changed during the day and between seasons but followed a similar diurnal pattern. The redox potential recorded at Bannister Creek varied from a minimum of -14 mV on 22 November 2002 to a maximum of 81 mV on 24 May 2003 (Figure 5.18). At Wanneroo, the redox potential was slightly higher than that recorded at Bannister Creek, reaching a maximum of 65 mV. All the 24 hour sample sets at Bannister Creek showed a gradual drop in redox potential from midnight to the early afternoon (around 13.00 hrs to 15.00 hrs), rising back to the same level around 16.00 hrs and then maintaining this level until midnight.

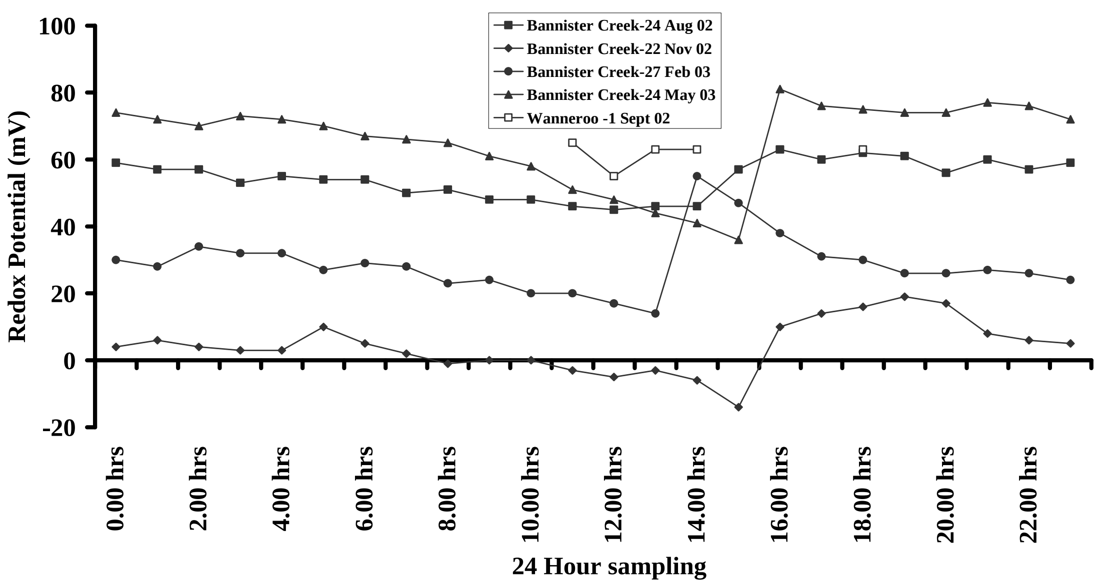


Figure 5.18 Redox potential measured in the hourly water samples taken over 24 hours from the drains at Bannister Creek in each season and at Wanneroo (in September 2002) between April 2002 and May 2003.

5.2.3 Major Storm Event Samples

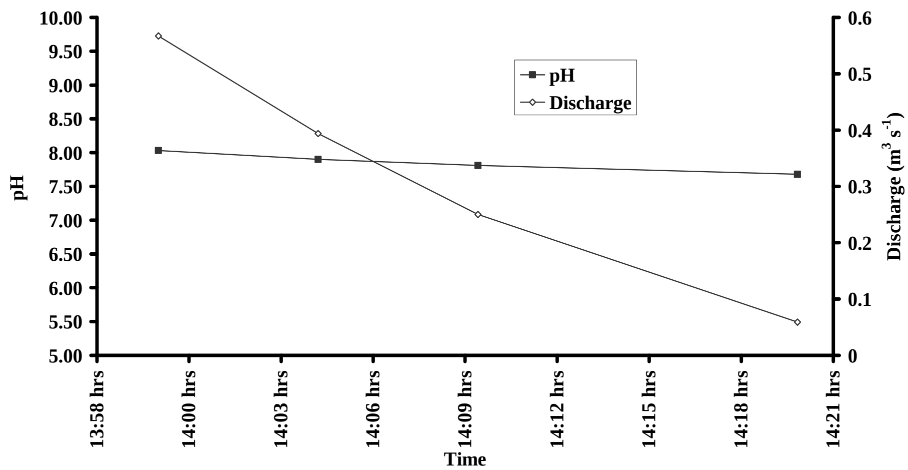
The physico-chemical parameters recorded during storm events at Bannister Creek and Wanneroo are shown in Table 5.3.

Table 5.3 Physico-chemical parameters of major storm event samples at Bannister Creek and Wanneroo

Parameter	pH	Conductivity	Temperature	Turbidity	Dissolved Oxygen		Redox Potential
		$\mu S\ cm^{-1}$	^oC	NTU	$mg\ L^{-1}$	% Saturation	mV
BANNISTER CREEK							
Range	7.68-8.03	140-163	16.4-17.6	0-1.3	9.3-9.4	96-98	53-60
Mean ± SE	7.86 ± 0.07	151 ± 5.07	16.9 ± 0.25	0.7 ± 0.30	9.4 ± 0.03	97 ± 0.31	56 ± 1.55
Median	7.86	150	16.8	0.8	9.4	97	55
WANNEROO							
Range	8.11-8.65	48-69	20.2-26.3	2.7-3.2	5.2-5.5	57-60	79-98
Mean ± SE	8.27 ± 0.08	61 ± 4.06	21.5 ± 0.97	2.9 ± 0.07	5.3 ± 0.05	59 ± 0.42	90 ± 2.65
Median	8.21	66	20.6	2.9	5.3	59	90

At both sites, the pH of major storm event samples changed little during each event recorded, with a mean (±se) of 7.86 ± 0.07 at Bannister Creek and 8.27 ± 0.08 at Wanneroo (Figure 5.19). The pH at Bannister Creek showed significant correlation with discharge with a very strong relationship ($P < 0.001$; $r = 0.999$). During another storm event at Bannister Creek on 9 August 2002, pH was recorded at 7.37. This was in the same range as the pH during the storm event on 14 September 2002. At Wanneroo, however, the pH was slightly higher than at Bannister Creek and showed no correlation with discharge ($P > 0.05$; $r = 0.14$).

a) Bannister Creek 14 September 2002



b) Wanneroo 11 April 2003

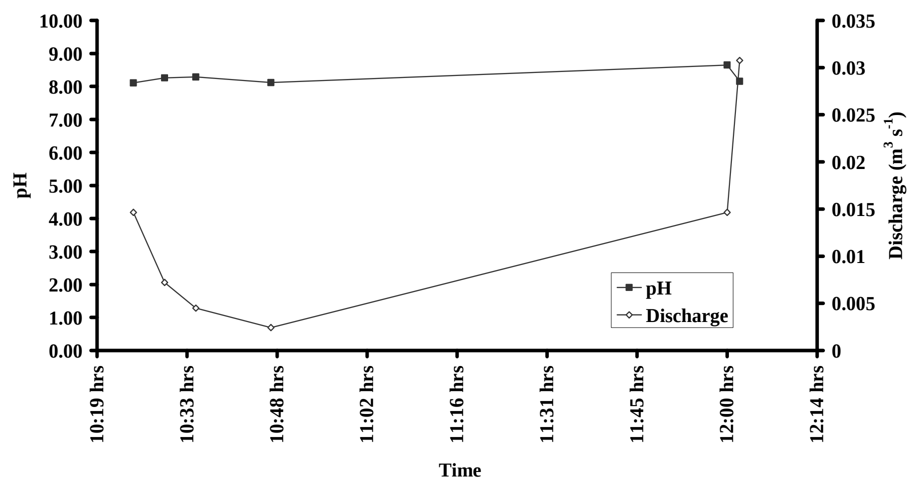
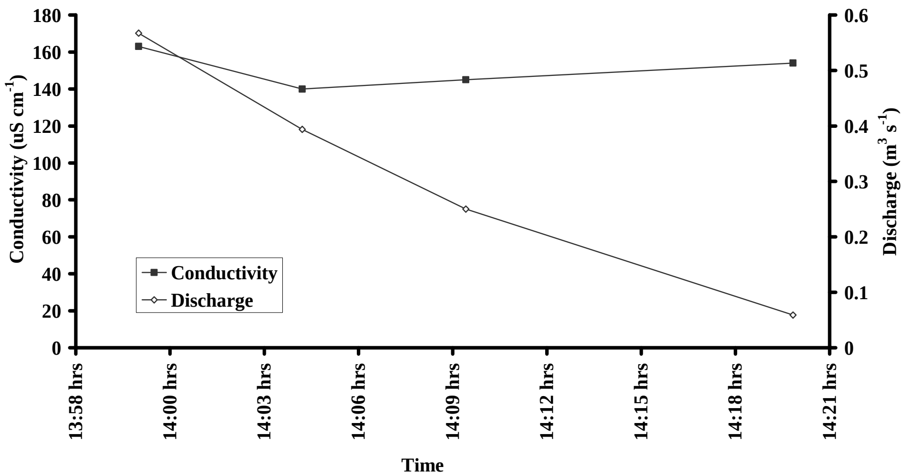


Figure 5.19 Time series of discharge and pH in major storm events captured at a) Bannister Creek on 14 September 2002 and b) Wanneroo on 11 April 2003.

Conductivity varied little during the storm events, ranging between 140-170 μS cm^{-1} at Bannister Creek and 50-70 μS cm^{-1} at Wanneroo with a mean (±se) of 151 ± 5.07 μS cm^{-1} at Bannister Creek and 61 ± 4.06 μS cm^{-1} at Wanneroo (Figure 5.20). The conductivity at Bannister Creek showed no correlation with discharge ($P > 0.05$; $r = 0.27$). During another storm event at Bannister Creek on 9 August 2002, conductivity was recorded at 134 μS cm^-

[1]. This was within the same range of the storm event on 14 September 2002. At Wanneroo the conductivity was lower than at Bannister Creek and showed no correlation with discharge ($P > 0.05$; $r = 0.71$).

a) Bannister Creek 14 September 2002



b) Wanneroo 11 April 2003

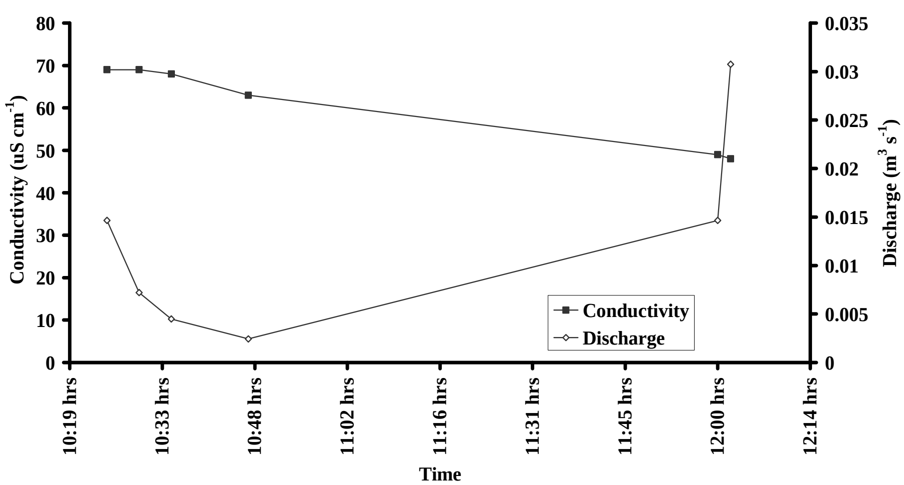
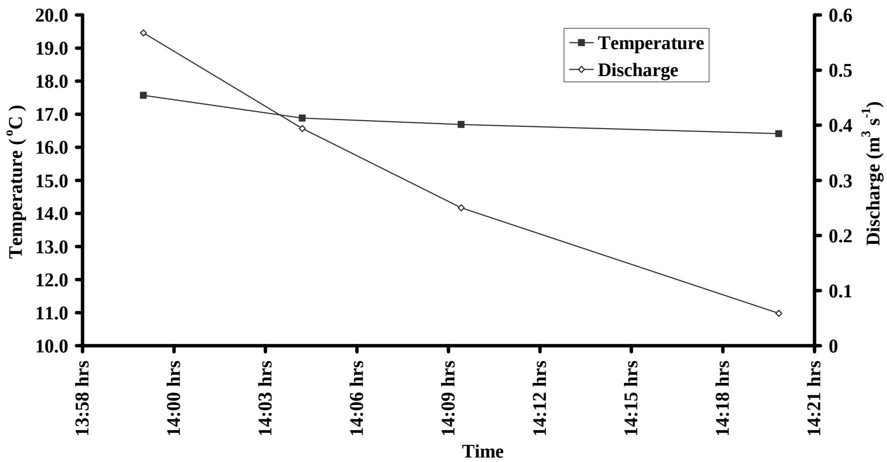


Figure 5.20 Time series of discharge and conductivity in major storm event captured at a) Bannister Creek on 14 September 2002, and b) Wanneroo on 11 April 2003.

The temperature of samples during the storm event at Bannister Creek on 14 September 2002 was quite consistent with a mean (± se) of 16.9 ± 0.25 °C. At Wanneroo on 11 April 2003 the sample temperature dropped by 5 °C at the beginning of the falling limb before becoming constant with a mean (± se) of 21.5 ± 0.97 ^{o}C (Figure 5.21). The temperature at Bannister Creek showed no significant correlation with discharge ($P > 0.05$; $r = 0.96$). During another storm event at Bannister Creek on 9 August 2002, the temperature was recorded at 17.5 ^{o}C, which was in the same range as during the storm event on 14 September 2002. There was no real change but a suggestion that it was slightly higher at higher discharges. At Wanneroo the temperature was slightly higher than at Bannister Creek and showed no correlation with discharge ($P > 0.05$; $r = 0.04$).

a) Bannister Creek 14 September 2002



b) Wanneroo 11 April 2003

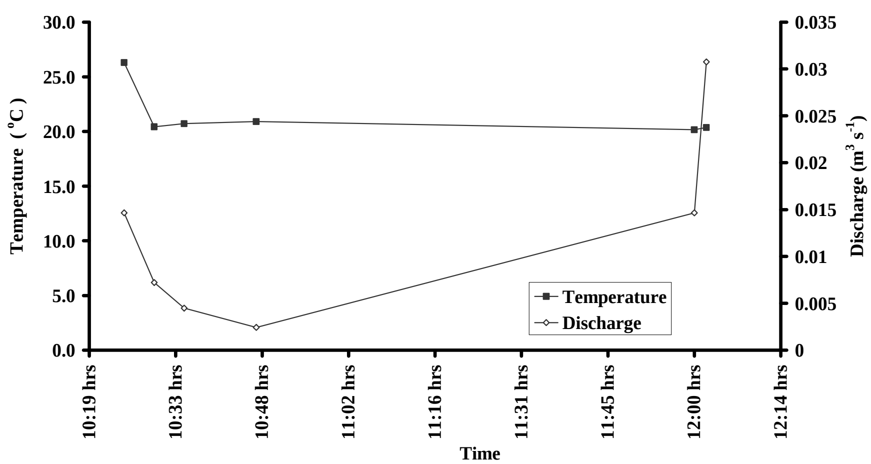
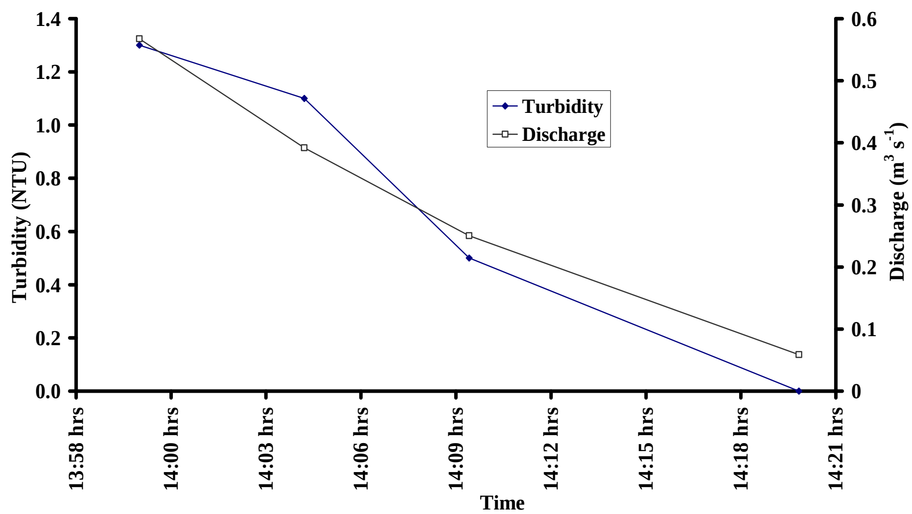


Figure 5.21 Time series of discharge and temperature in major storm event captured at a) Bannister Creek on 14 September 2002, and b) Wanneroo on 11 April 2003.

Turbidity changed slightly during the storm event, ranging between 0 and 1.3 NTU at Bannister Creek and 2.7 and 3.0 NTU at Wanneroo (Figure 5.22). A relationship between turbidity and discharge seemed positive at Bannister Creek but there was no apparent relationship at Wanneroo. Turbidity at Bannister Creek showed significantly strong correlation to discharge ($P < 0.05$; $r = 0.98$). During another storm event at Bannister Creek on 9 August 2002, turbidity was recorded at 0.4 NTU which was within the same range of the storm event on 14 September 2002. At Wanneroo the turbidity was slightly higher than at Bannister Creek and showed no correlation with discharge ($P > 0.05$; $r = 0.001$).

a) Bannister Creek 14 September 2002



b) Wanneroo 11 April 2003

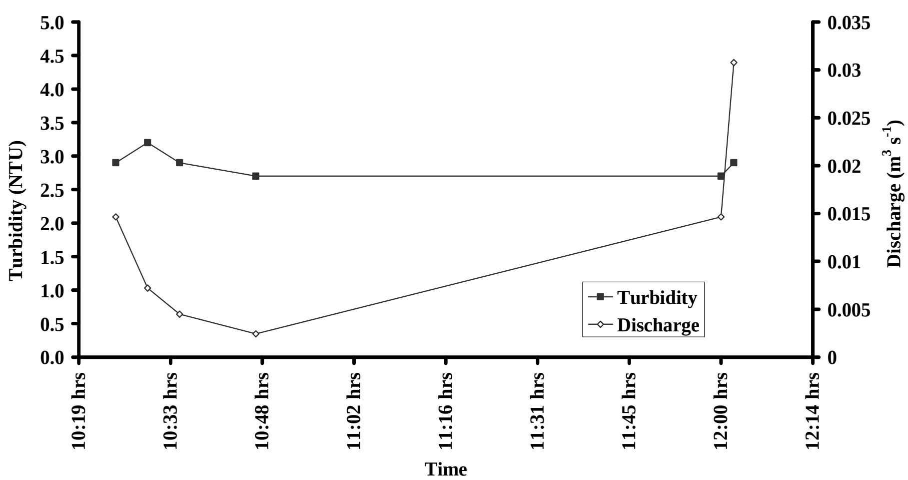
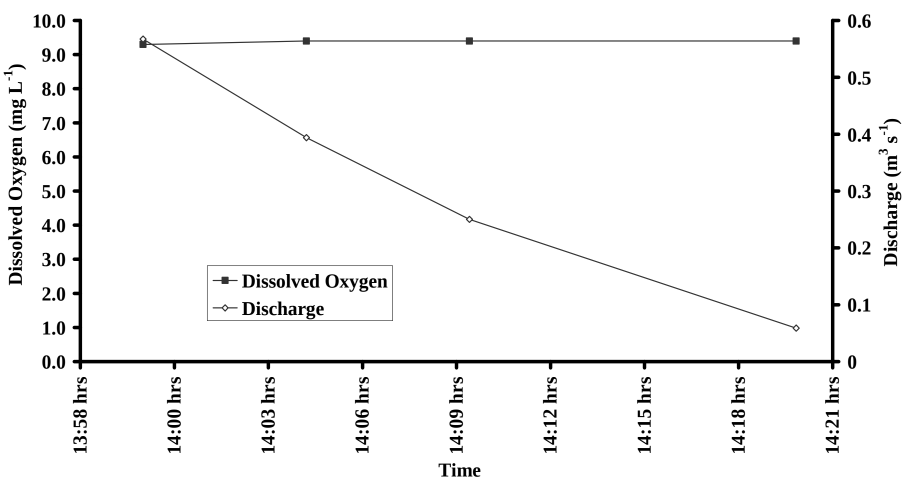
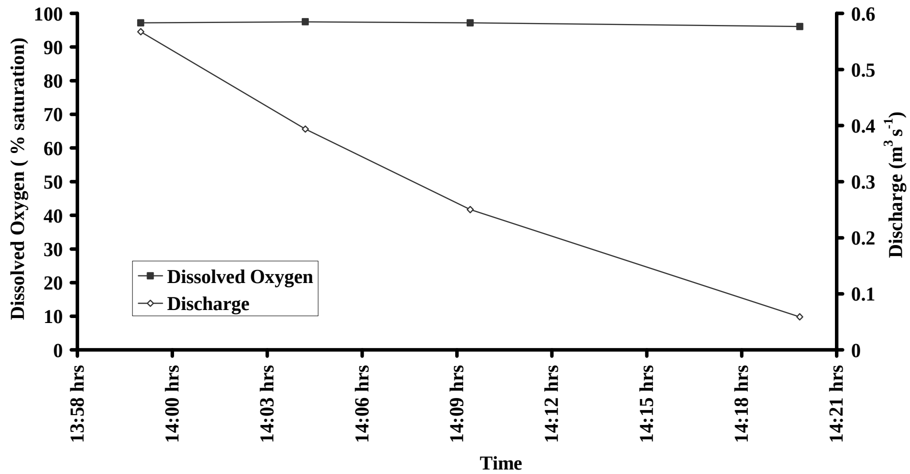


Figure 5.22 Time series of discharge and turbidity in major storm event captured at a) Bannister Creek on 14 September 2002 and b) Wanneroo on 11 April 2003.

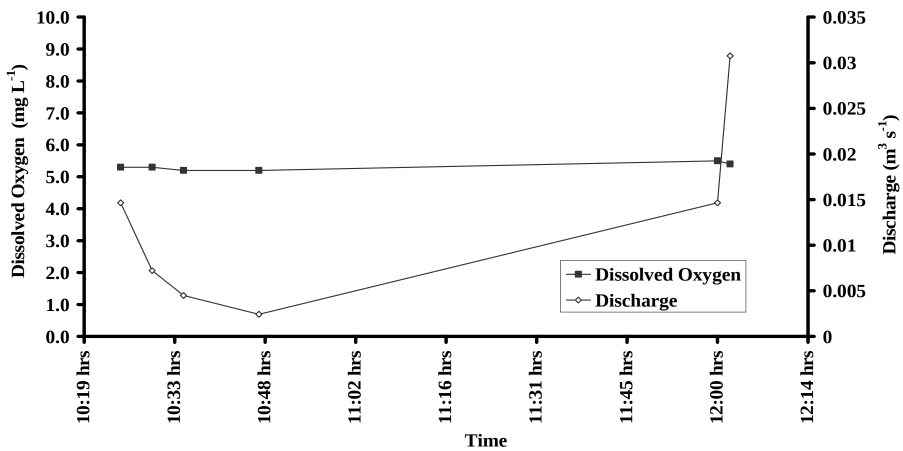
At both sites, the dissolved oxygen in storm event samples was very consistent over the storm events, ranging between 9 and 10 mg L^{-1} with a mean (±se) of 9.4 ± 0.03 mg L^{-1} at Bannister Creek (Figure 5.23a) and 5 and 6 mg L^{-1} with a mean (±se) of 5.3 ± 0.05 mg L^{-1} at Wanneroo (Figure 5.23b). All the storm event sample sets showed moderate dissolved oxygen saturations with a mean (± se) of 97 ± 0.31% at Bannister Creek and of 59.04 ± 0.42% at Wanneroo. Neither the DO concentration nor % saturation at Bannister Creek showed any significant correlation with discharge ($P > 0.05$; $r = 0.77$ for both DO concentration and % saturation). During another storm event at Bannister Creek on 9 August 2002, DO concentration and percentage saturation were recorded at 9.5 mg L^{-1} and 99% respectively, which was in the same range as during the storm event on 14 September 2002. At Wanneroo the DO concentration and percentage saturation were lower than at Bannister Creek and showed no correlation with discharge ($P > 0.05$; $r = 0.70$, and 0.76 respectively).

a) Bannister Creek 14 September 2002





b) Wanneroo 11 April 2003



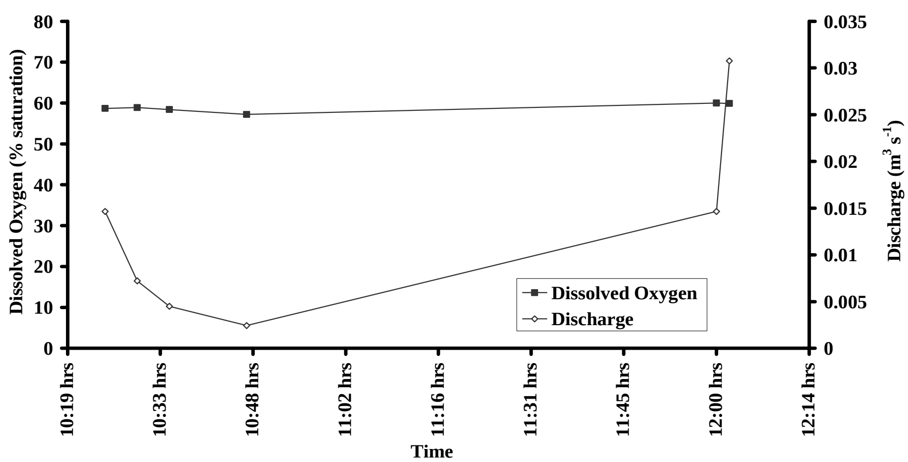
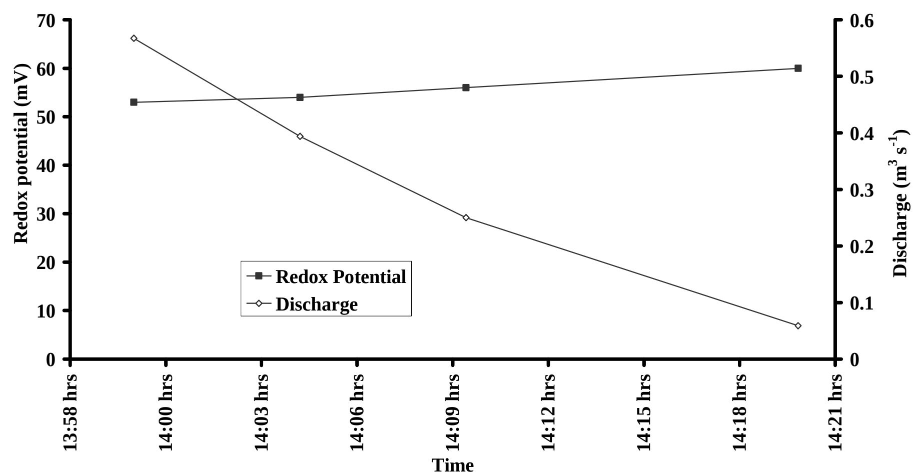


Figure 5.23 Time series of discharge/dissolved oxygen concentration and discharge/percentage saturation in a major storm event captured at a) Bannister Creek on 14 September 2002 and b) Wanneroo on 11 April 2003.

At both sites, the redox potential was variable over the storm events, ranging between 53 and 60 mV with a mean (± se) of 56 ± 1.55 mV at Bannister Creek (Figure 5.24a) and 79 and 98 mV with a mean (± se) of 90 ± 2.65 mV at Wanneroo (Figure 5.24b). The redox potential of all the storm event sample sets did not change greatly but appeared to be lower at higher flows. During another storm event at Bannister Creek on 9 August 2002, redox potential was recorded at 48 mV, which was within the same range as the storm event on the 14 September 2002. The redox potential at Bannister Creek showed a significant correlation with discharge with a strong relationship ($P < 0.05$; $r = 0.96$). At Wanneroo the redox potential was higher than at Bannister Creek and showed no significant correlation with discharge ($P > 0.05$; $r = 0.96$).

a) Bannister Creek 14 September 2002



b) Wanneroo 11 April 2003

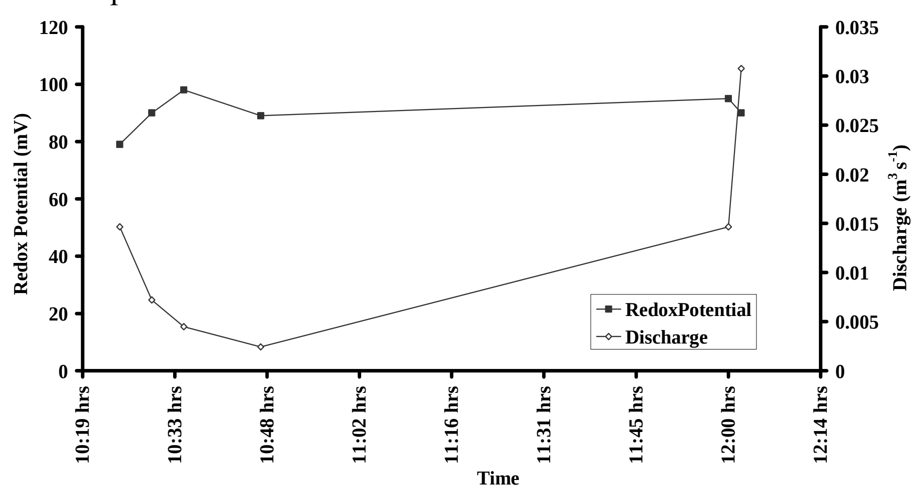


Figure 5.24 Time series of discharge and redox potential in a major storm event captured at a) Bannister Creek on 14 September 2002 and b) Wanneroo on 11 April 2003.

5.2.4 Groundwater Samples

The physico-chemical parameters of groundwater samples collected at Bannister Creek and Wanneroo are shown in Table 5.4.

Table 5.4 Physico-chemical parameters of groundwater samples at Bannister Creek and Wanneroo collected between October 2002 and May 2003

Parameter	Oct-02	Nov-02	Dec-02	Jan-03	Feb-03	Mar-03	Apr-03	May-03
BANNISTER CREEK								
pH								
Range	7.19-7.92	6.9-7.81	7.32-7.84	6.77-7.72	6.70-7.88	7.38-7.71	6.88-7.61	7.03-7.81
Mean ± SE	7.58 ± 0.21	7.24 ± 0.29	7.63 ± 0.16	7.14 ± 0.29	7.14 ± 0.37	7.60 ± 0.11	7.22 ± 0.21	7.37 ± 0.23
Median	7.63	7	7.74	6.94	6.83	7.7	7.16	7.28
Conductivity (µS cm^{-1})								
Range	460-623	262-524	453-631	431-619	463-618	457-621	431-615	434-604
Mean ± SE	528 ± 49	423 ± 81	545 ± 52	533 ± 55	549 ± 46	551 ± 49	535 ± 55	530 ± 50
Median	502	483	550	550	567	575	559	553
Temperature (^oC)								
Range	19.95-21.94	20.75-22.56	21.37-23.99	21.24-23.75	22.95-23.15	21.44-22.26	20.86-22.57	20.15-22.08
Mean ± SE	21.08 ± 0.59	21.36 ± 0.59	22.47 ± 0.79	22.21 ± 0.78	23.02 ± 0.06	21.78 ± 0.25	21.54 ±0.52	21.05 ± 0.56
Median	21.35	20.78	22.04	21.65	22.97	21.64	21.2	20.92
Turbidity (NTU)								
Range	1.5-4.1	1.8-3	3.5-4.7	3.2-5.1	5.5-6.6	3-5.1	0-4.5	0-0.3
Mean ± SE	2.87 ± 0.75	2.57 ± 0.38	4 ± 0.36	4.2 ± 0.55	5.93 ± 0.34	4.1 ± 0.61	2.63 ± 1.35	0.1 ± 0.1
Median	3	2.9	3.8	4.3	5.7	4.2	3.4	0
WANNEROO								
pH								
Range	7.75 -7.82	7.53-8.24	7.45-8.05	7.67-8.05	7.65-7.9	8.04-8.25	7.42-7.68	7.68-7.83
Mean ± SE	7.78 ± 0.21	7.78 ± 0.23	7.7 ± 0.18	7.86 ± 0.11	7.81 ± 0.08	8.14 ± 0.06	7.53 ± 0.08	7.74 ± 0.05
Median	7.76	7.57	7.6	7.85	7.88	8.12	7.48	7.7
Conductivity (µS cm^{-1})								
Range	915-1008	888-981	892-988	920-997	954-1005	949-1010	918-1036	880-1055
Mean ± SE	956 ± 28	943 ± 28	944 ± 28	947 ± 25	973 ± 16	970 ± 20	975 ± 34	977 ± 51
Median	944	960	951	923	961	951	970	996
Temperature (^oC)								
Range	20.57-22.47	20.82 ± 26.67	21.75 - 22.42	22.23-23.16	21.9-23	21.65-22.54	20.63-22.91	20.98-22.70
Mean ± SE	21.39 ± 0.56	23.23 ± 1.77	22 ± 0.21	22.74 ± 0.27	22.35 ± 0.33	21.99 ± 0.28	21.88 ± 0.67	21.94 ± 0.51
Median	21.13	22.2	21.82	22.84	22.15	21.79	22.1	22.14
Turbidity (NTU)								
Range	2.6-3.2	1.7-4.8	3.4-5.2	5.6-5.8	5.3-6	4.1-5.4	0-3.7	0-4.3
Mean ± SE	2.83 ± 0.19	2.97 ± 0.94	4.03 ± 0.58	5.7 ± 0.06	5.67 ± 0.20	4.67 ± 0.38	2.33 ± 1.17	2.17 ± 1.24
Median	2.7	2.4	3.5	5.7	5.7	4.5	3.3	2.2

The pH of groundwater samples at Wanneroo (7.53-8.14) was consistently higher than at Bannister Creek (7.14-7.63) (Figure 5.25).

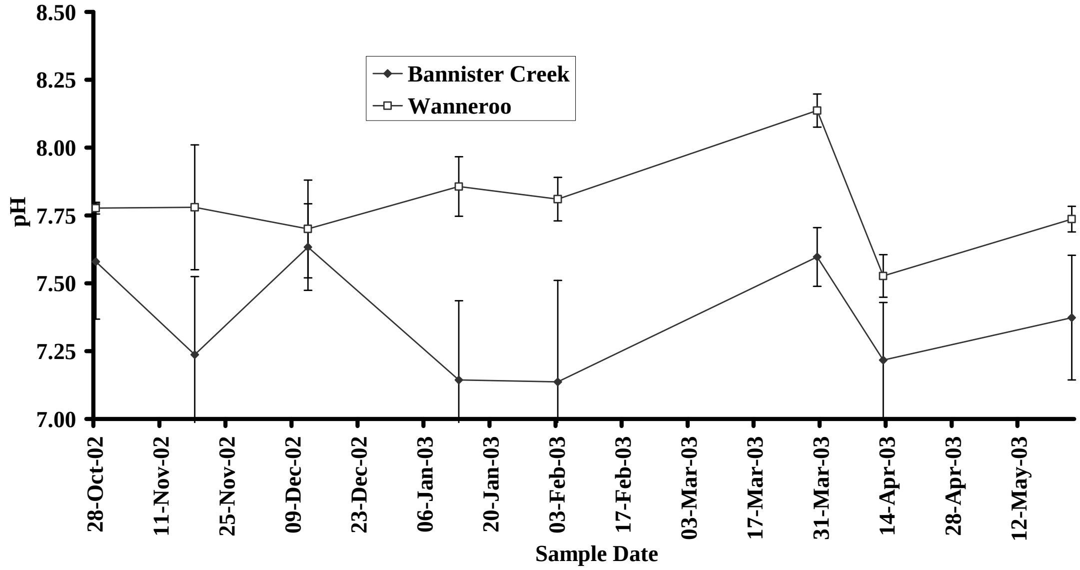


Figure 5.25 Mean (±SE) monthly pH of groundwater measured during the regular sampling program at Bannister Creek and Wanneroo between April 2002 and May 2003.

Conductivity of groundwater samples was very consistent and at Wanneroo was consistently higher than at Bannister Creek by approximately 400 μS cm^{-1} (Figure 5.26). Conductivity varied between 943 and 977 μS cm^{-1} at Wanneroo and 423 and 545 μS cm^{-1} at Bannister Creek.

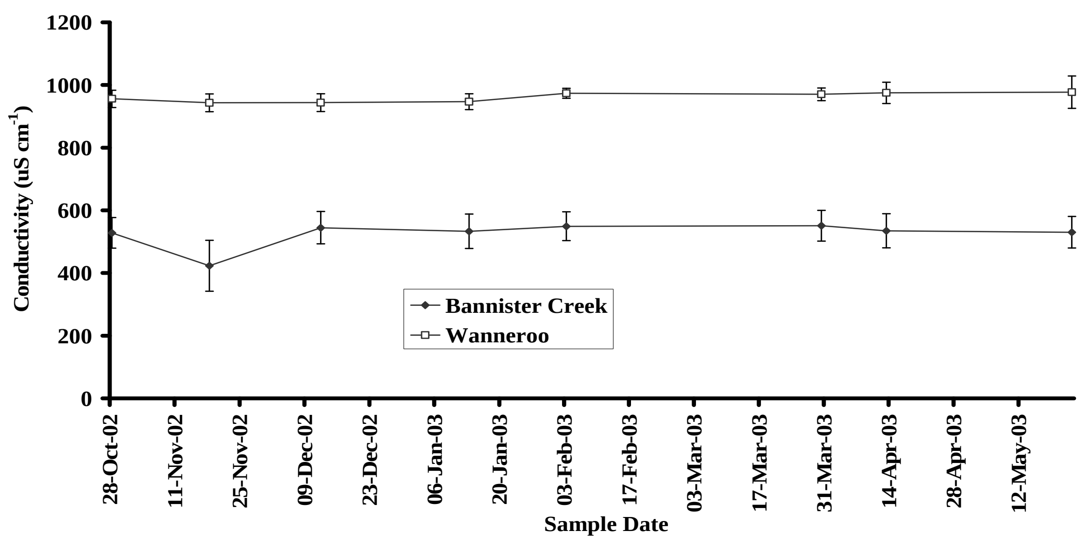


Figure 5.26 Mean (± SE) monthly conductivity of groundwater measured during regular sampling program at Bannister Creek and Wanneroo between April 2002 and May 2003.

At both sites, temperature of groundwater samples was very consistent at around 22 ºC (Figure 5.27). It was slightly higher at Wanneroo than at Bannister Creek by 0.5 ºC. It varied between 21.4 and 23.2 ºC at Wanneroo and between 21.1 and 23 ºC at Bannister Creek.

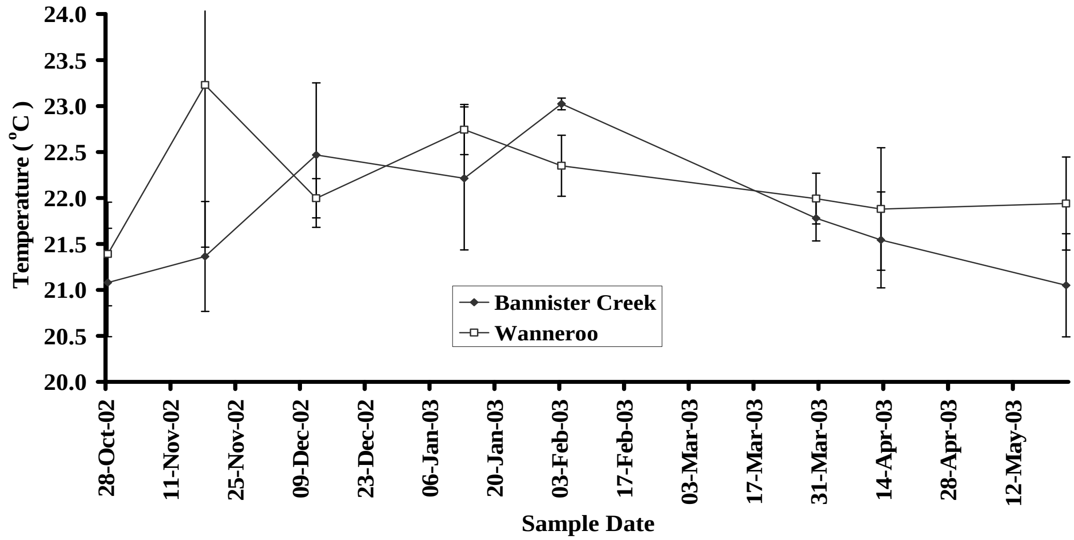


Figure 5.27 Mean (± SE) monthly temperature of groundwater measured during the regular sampling program at Bannister Creek and Wanneroo between April 2002 and May 2003.

Turbidity of groundwater samples at Wanneroo was similar to Bannister Creek (Figure 5.28). It varied between 2.2 and 5.7 NTU at Wanneroo and 2.6 and 5.9 NTU at Bannister Creek. At both sites, the turbidity of groundwater samples peaked in summer between early January and the end of March 2003.

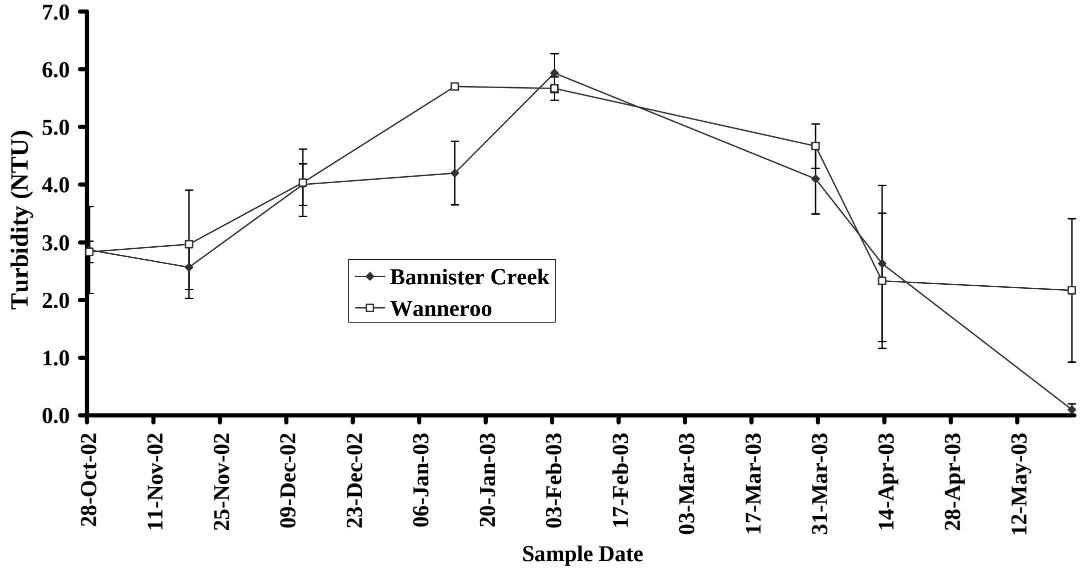


Figure 5.28 Mean (± se) monthly turbidity of groundwater measured during the regular sampling program at Bannister Creek and Wanneroo between April 2002 and May 2003.

5.3 Nutrient Concentration of Water Samples

5.3.1 Routine Samples

The daily nutrient concentrations found in routine samples at Bannister Creek and Wanneroo are shown in Table 5.5.

5.3.1.1 Nitrogen Concentrations

At both sites, the TN concentrations of routine samples were generally higher and highly variable during peak flows (Figure 5.29a). At Bannister Creek, the TN concentration of routine samples varied from a minimum of 0.381 mg L^{-1} on 6 May 2002 to a maximum of 3.663 mg L^{-1} on 18 April 2002 with a mean (± se) of 1.45 ± 0.03 mg L^{-1}. TN concentrations on 8 May 2003 peaked at 2.68 mg L^{-1} and this was mainly caused by a peak in ammonium (see below). The relative proportions of TN:NH_4:NOx changed throughout the year in a similar pattern with a mean ratio of 20:1:8. TN concentrations showed significant but weak correlation with discharge at Bannister Creek ($P < 0.001$; $r = 0.21$). At Wanneroo, TN concentration varied from a minimum of 0.125 mg L^{-1} on 12 July 2002 to a maximum of 1.957 mg L^{-1} on 7 August 2002 with a mean (± se) of 0.523 ± 0.08 mg L^{-1}. The relative proportions of TN:NH_4:NOx varied throughout the year with the mean ratio 8:1:1.3. TN concentrations showed no correlation with discharge ($P > 0.05$; $r = 0.04$).

Table 5.5 Daily nutrient concentrations of routine samples at Bannister Creek and Wanneroo

Parameter	TN mg L^{-1}	NH_4 mg L^{-1}	NOx mg L^{-1}	TP mg L^{-1}	FRP mg L^{-1}	TSS mg L^{-1}
BANNISTER CREEK						
Range	0.381-3.663	0.015-1.246	0.013-2.151	0.041-0.234	0.024-0.192	0.2-41
Mean ± SE	1.445 ± 0.033	0.069 ± 0.007	0.553 ± 0.031	0.107 ± 0.003	0.005 ± 0.002	6 ±0.382
Median	1.417	0.065	0.445	0.103	0.048	6.000
WANNEROO						
Range	0.125-1.957	0.002-0.383	0.002-0.770	0.011-0.239	0.009-0.167	0.2-64.556
Mean ± SE	0.523 ± 0.077	0.068 ± 0.016	0.087 ± 0.028	0.068 ± 0.011	0.031 ± 0.007	11.23 ±2.79
Median	0.400	0.043	0.053	0.047	0.018	6.800

At both sites, the NH_4 concentrations of routine samples were generally high and variable during peak flows (Figure 5.29b). At Bannister Creek, NH_4 concentrations ranged from a minimum of 0.015 mg L^{-1} on 4 March 2003 to a maximum of 1.246 mg L^{-1} on 8 May 2003 with a mean (± se) of 0.069 ± 0.007 mg L^{-1}. NH_4 concentrations showed no correlation with discharge ($P > 0.05$; $r = 0.041$). At Wanneroo, NH_4 concentration varied from a minimum of 0.002 mg L^{-1} on 10, 12, 31 July 2002 to a maximum of 0.383 mg L^{-1} on 13 April 2003 with a mean (± se) of 0.068 ± 0.016 mg L^{-1} and showed no correlation with discharge ($P > 0.05$; $r = 0.47$). NH_4 concentrations of routine samples at Bannister Creek were generally higher than at Wanneroo but on some occasions were lower, for example, between August and October 2002.

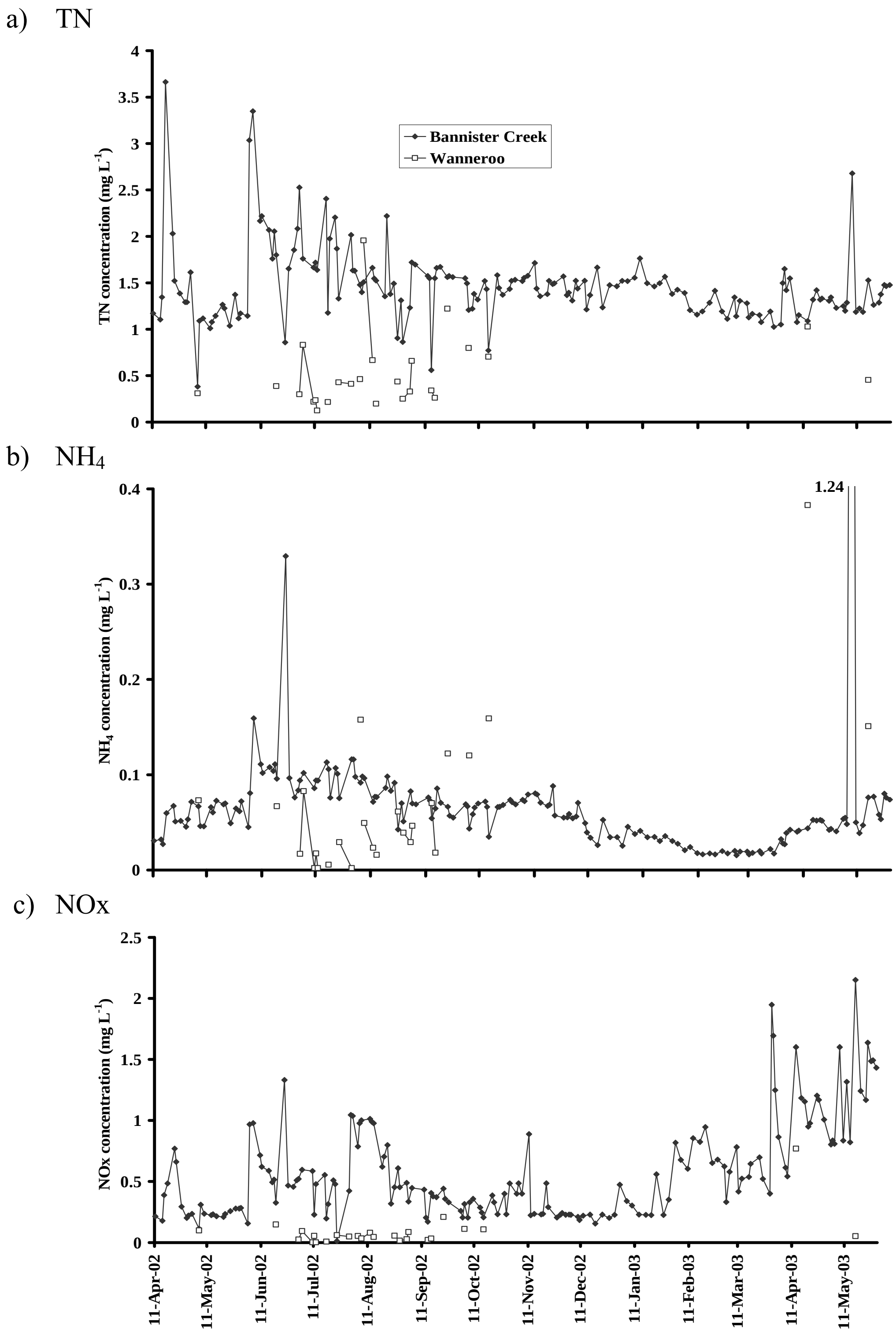


Figure 5.29 Nitrogen concentrations a) TN, b) Ammonium, and c) NOx measured during the regular sampling program at Bannister Creek and Wanneroo between April 2002 and May 2003.

At Bannister Creek, the NOx concentrations of routine samples varied throughout the year with small changes in winter but large increases in autumn, whereas they were consistently low at Wanneroo (Figure 5.29c). At Bannister Creek, they ranged from a minimum of 0.013 mg L^{-1} on 24 July 2002 to a maximum of 2.151 mg L^{-1} on 17 May 2003 with a mean (± se) of 0.553 ± 0.03 mg L^{-1} and showed no correlation with discharge ($P > 0.05$; $r = 0.067$). At Wanneroo, the NOx concentration varied from a minimum of 0.002 mg L^{-1} on 10 and 12 July 2002 to a maximum of 0.770 mg L^{-1} on 13 April 2003 with a mean (± se) of 0.087 ± 0.028 mg L^{-1} and showed no significant correlation with discharge ($P > 0.05$; $r = 0.62$). The NOx concentrations of routine samples at Bannister Creek were higher than those at Wanneroo.

5.3.1.2 Phosphorus and Total Suspended Solid (TSS) Concentrations

TP concentrations of routine samples were highly variable at both sites throughout the year (Figure 5.30a), ranging from a minimum of 0.041 mg L^{-1} on 17 March 2003 to a maximum of 0.234 mg L^{-1} on 4 June 2002 with a mean (± se) of 0.107 ± 0.003 mg L^{-1} at Bannister Creek and from a minimum of 0.011 mg L^{-1} on 18 July 2002 to a maximum of 0.239 mg L^{-1} on 7 August 2002 with a mean (± se) of 0.068 ± 0.011 mg L^{-1} at Wanneroo. The relative proportions of TP to FRP changed throughout the year with the mean ratio of 21:1 at Bannister Creek and 2:1 at Wanneroo. TP concentrations were significantly correlated to discharge with a very weak relationship ($P < 0.001$; $r = 0.25$) at Bannister Creek but showed no correlation with discharge ($P > 0.05$; $r = 0.18$) at Wanneroo. TP concentrations of routine samples at Wanneroo seemed lower than at Bannister Creek but on some occasions rose up to the same level as Bannister Creek in spring and autumn.

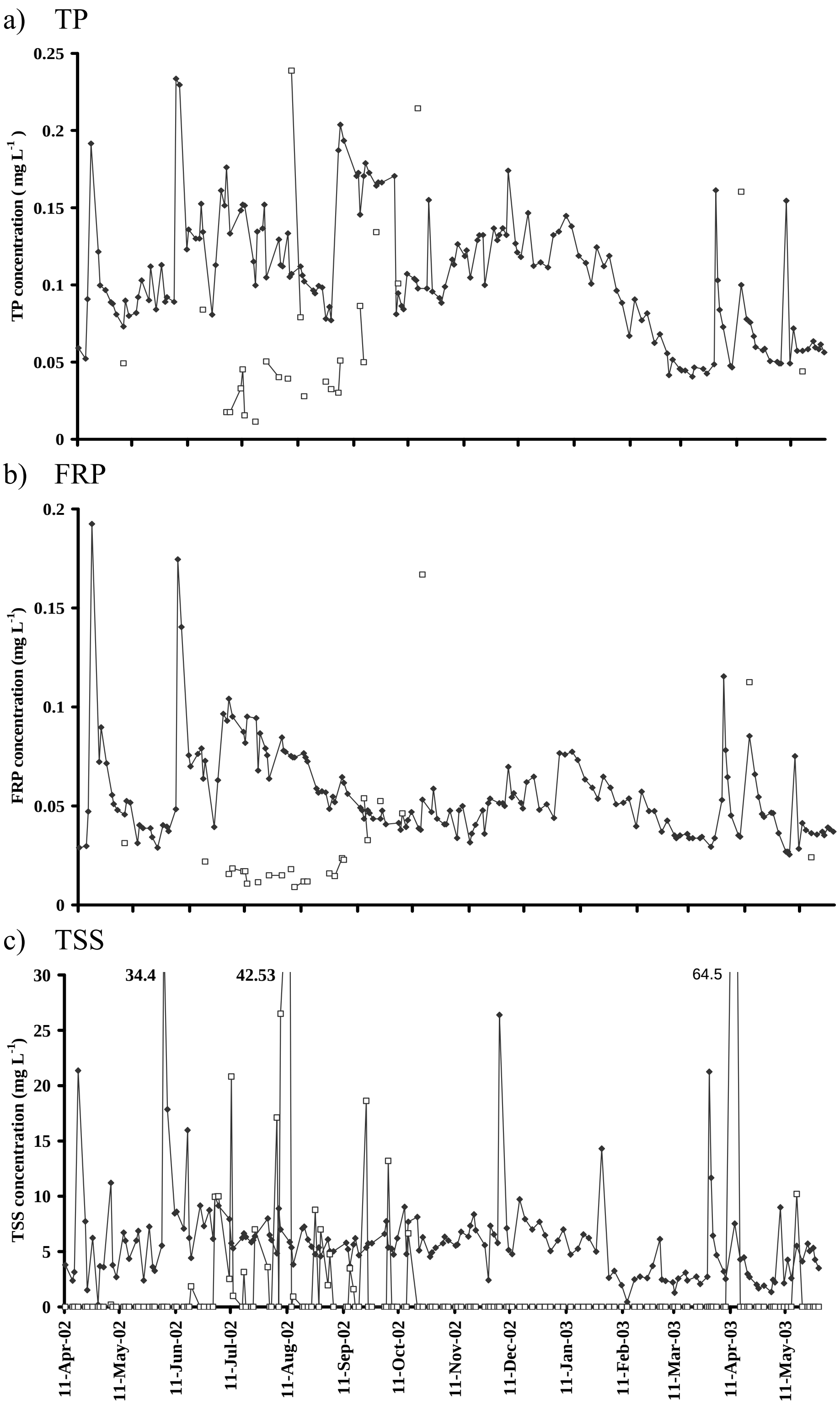


Figure 5.30 Phosphorus and total suspended solid (TSS) concentrations a) TP, b) FRP, and c) TSS measured during the regular sampling program at Bannister Creek and Wanneroo between April 2000 and May 2003.

FRP concentrations of routine samples at both sites varied during the year (Figure 5.30b) from a minimum of 0.025 mg L^{-1} on 5 May 2003 to a maximum of 0.192 mg L^{-1} on 18 April 2002 with a mean (± se) of 0.055 ± 0.002 mg L^{-1} at Bannister Creek and from a minimum of 0.009 mg L^{-1} on 7 August 2002 to a maximum of 0.167 mg L^{-1} on 16 October 2002 with a mean (± se) of 0.031 ± 0.007 mg L^{-1} at Wanneroo. FRP concentrations were significantly correlated to discharge with a weak relationship ($P < 0.001$; $r = 0.35$) at Bannister Creek but showed no correlation with discharge ($P > 0.05$; $r = 0.36$) at Wanneroo. The FRP concentrations of routine samples at Wanneroo were generally lower than at Bannister Creek but were similar to Bannister Creek in spring and autumn.

TSS concentrations of routine samples were very consistent in Bannister Creek except for a few peaks in summer and early autumn (Figure 5.30c). However, they were very peaky during high flow in winter at Wanneroo. Seasonal changes at Bannister Creek showed an effect on TSS concentration with discharge high in winter but low in summer. They varied from a minimum of 0.0002 g L^{-1} on 29 April, 2002 to a maximum of 0.043 g L^{-1} on 10 August, 2002 with a mean (± se) of 0.006 ± 0.004 g L^{-1} at Bannister Creek and between 0.0002 and 0.065 g L^{-1} with a mean (± se) of 0.011 ± 0.003 g L^{-1} at Wanneroo. TSS concentrations were significantly correlated with discharge ($P < 0.001$; $r = 0.40$) at Bannister Creek and there was no correlation ($P > 0.05$; $r = 0.30$) at Wanneroo.

It is clearly seen that TN, TP, FRP and TSS concentration at Bannister Creek and NH_4 concentration at Wanneroo showed significant correlations with discharge (Figure 5.31). However the relationships of all parameters were weak with $r = 0.21$ for TN, $r = 0.25$ for TP, $r = 0.35$ for FRP, and $r = 0.40$ for TSS at Bannister Creek and $r = 0.47$ for NH_4 at Wanneroo (see below). The LOWESS line shows the relationship between two parameters in a scattering characteristic by trying to fit the line through those scattering points in such a way that the average relationship is depicted.

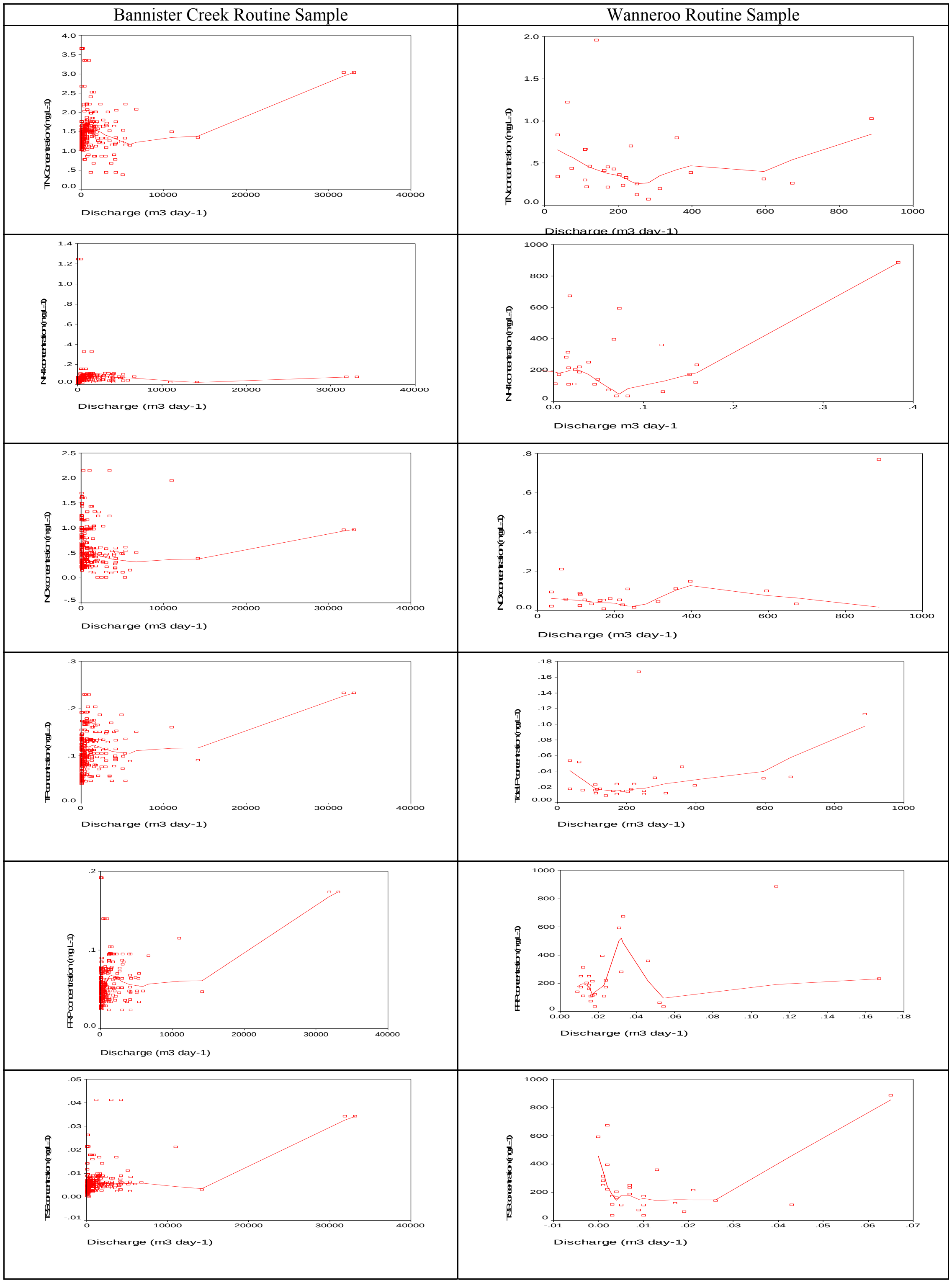


Figure 5.31 Relationships between nutrient concentration and discharge from routine samples at Bannister Creek and Wanneroo sites. (The line showing in each graph is the LOWESS line (SPSS Inc).

5.3.2 Twenty Four Hour Sampling

The nutrient concentrations of the 24 hour sampling period water samples at the Bannister Creek and Wanneroo sites are shown in Table 5.6. In Bannister Creek values from the 24 hour sampling agree well with the regular sampling program.

Table 5.6 Nutrient concentrations of the 24 hour sampling period water samples at Bannister Creek and Wanneroo

Parameter	Total N mg L-1	NH_4 mg L-1	NOx mg L-1	Total P mg L-1	FRP mg L-1	TSS mg L-1
BANNISTER CREEK - 24 August 2002						
Range	0.835-2.956	0.059-0.206	0.186-0.769	0.070-0.352	0.032-0.073	2.716-60.737
Mean ± SE	1.376 ± 0.082	0.094 ± 0.008	0.484 ± 0.036	0.098 ± 0.011	0.056 ± 0.002	7.029 ± 2.340
Median	1.338	0.080	0.496	0.085	0.056	4.583
BANNISTER CREEK - 22 November 2002						
Range	1.173-1.496	0.045-0.064	0.171-0.388	0.1-0.126	0.026-0.064	5.917-8.071
Mean ± SE	1.317 ± 0.017	0.056 ± 0.001	0.253 ± 0.013	0.115 ± 0.001	0.045 ± 0.002	6.844 ± 0.099
Median	1.305	0.056	0.228	0.115	0.048	6.827
BANNISTER CREEK - 27 February 2002						
Range	1.056-1.379	0.010-0.034	0.397-0.698	0.062-0.087	0.031-0.048	1.533-5.385
Mean ± SE	1.164 ± 0.015	0.018 ± 0.001	0.614 ± 0.015	0.070 ± 0.001	0.040 ± 0.001	3.017 ± 0.20
Median	1.146	0.017	0.641	0.068	0.040	2.804
BANNISTER CREEK - 24 May 2003						
Range	1.034-1.464	0.037-0.056	0.822-1.637	0.049-0.072	0.035-0.049	0.20-5.706
Mean ± SE	1.269 ± 0.017	0.050 ± 0.001	1.388 ± 0.046	0.062 ± 0.001	0.042 ± 0.001	4.441 ± 0.209
Median	1.270	0.050	1.478	0.063	0.043	4.697
WANNEROO - 1 September 2002						
Range	0.60-0.329	0.011-0.039	0.002-0.107	0.015-0.021	0.023-0.032	0-5.706
Mean ± SE	0.143 ± 0.023	0.020 ± 0.002	0.023 ± 0.010	0.017 ± 0.001	0.025 ± 0.001	0.339 ± 0.148
Median	0.097	0.014	0.002	0.016	0.023	0.450

5.3.2.1 Nitrogen Concentrations

TN concentrations at Bannister Creek were relatively constant over the 24 hour period and between seasons, ranging between 1 and 1.5 mg L^{-1} (Figure 5.32a). However, they were very low, around 0.05 mg L^{-1}, at Wanneroo. At Bannister Creek, the TN concentration varied from a minimum of 0.835 mg L^{-1} at 20.00 hrs on 24 August 2002 to a maximum of 2.956 mg L^{-1} at 5.00 hrs on 24 August 2002 with a mean (± se) of 1.279 ± 0.023 mg L^{-1}. On 24 August 2002, the TN concentration peaked at almost 2 mg L^{-1} at 18.00 hrs. This was possibly linked to high ammonium (see below). At Wanneroo, the TN concentration was very low, varying from a minimum of 0.060 mg L^{-1} at 13.00 hrs on 1 September 2002 to a maximum of 0.329 mg L^{-1} at 18.00 hrs on 1 September 2002 with a mean (± se) of 0.143 ± 0.023 mg L^{-1}.

NH_4 concentrations were very similar over the 24 hour periods and between seasons at Bannister Creek, varying from a minimum of approximately 0.01 mg L^{-1} at 19.00 hrs on 27 February 2003 to a maximum of 0.206 mg L^{-1} at 18.00 hrs on 24 August 2003 with a mean (± se) of 0.054 ± 0.003 mg L^{-1} (Figure 5.32b). At Wanneroo, the NH_4 concentrations were very low, ranging from a minimum of 0.011 mg L^{-1} at 14.00 hrs on 1 September 2002 to a maximum of 0.039 mg L^{-1} at 18.00 hrs on 1 September, 2002 with a mean (± se) of 0.02 ± 0.002 mg L^{-1}.

NOx concentrations were more variable than NH_4 or TN during the 24 hour periods and between seasons at Bannister Creek (Figure 5.32c). Except for the 24 May 2003, NOx concentrations were very high, ranging from 0.8 mg L^{-1} to 1.6 mg L^{-1}. The NOx, concentrations accounted for a large proportion of TN. They varied from a minimum of 0.171 mg L^{-1} at 20.00 hrs on 22 November 2002 to a maximum of 1.637 mg L^{-1} at 16.00 hrs on 24 May 2003 with a mean (±se) of 0.685 ± 0.046 mg L^{-1}. At Wanneroo NOx concentrations were low at <0.002 mg L^{-1} except at 18.00 hrs where they peaked at 0.107 mg L^{-1}. The mean (±se) NOx concentration was 0.023 ± 0.010 mg L^{-1}.

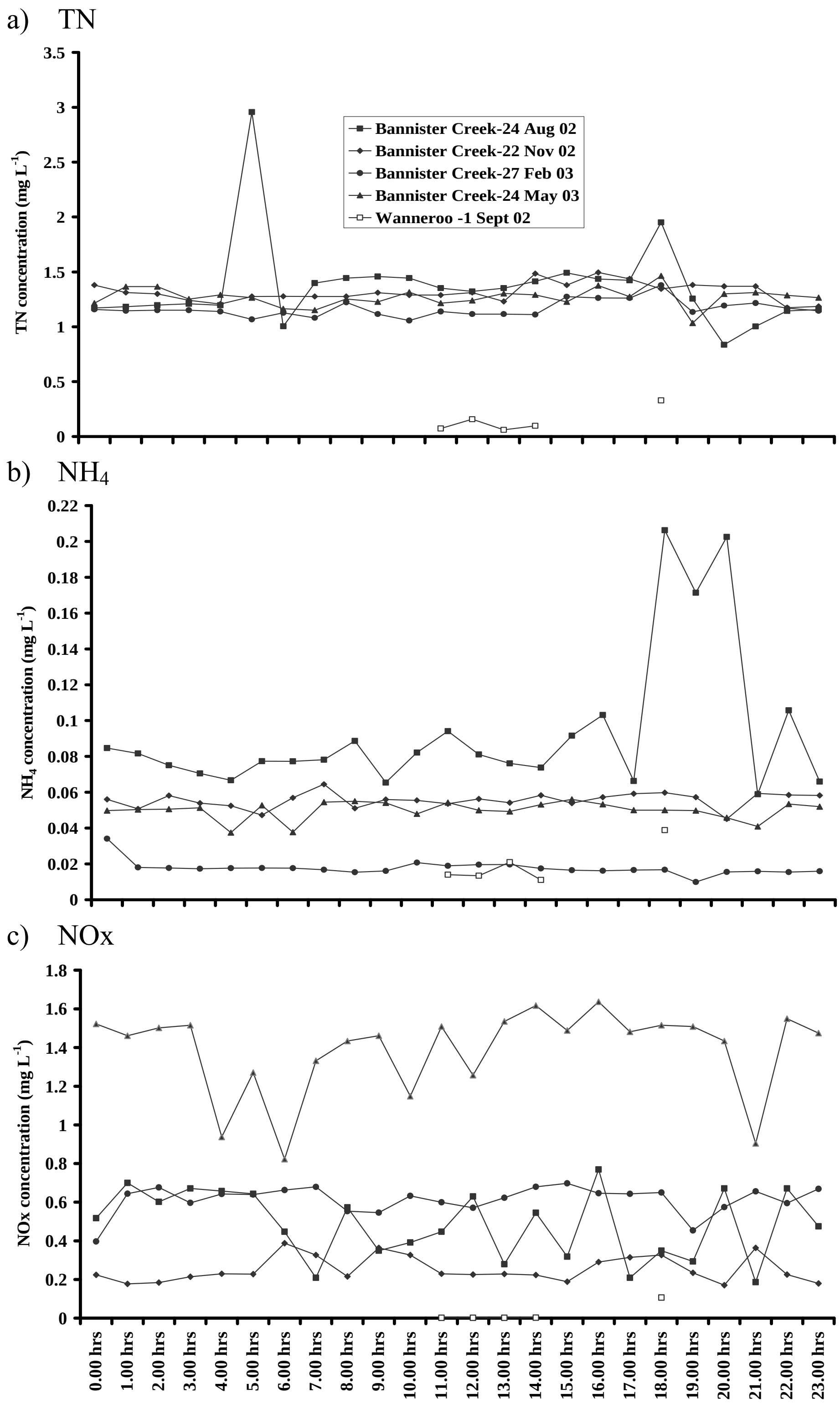


Figure 5.32 Nitrogen concentrations a) TN, b) NH_4 and c) NOx measured during the 24 hour sampling periods at Bannister Creek and Wanneroo.

5.3.2.2 Phosphorus and Total Suspended Solid (TSS) Concentrations

At both sites, the TP concentration of the 24 hour sampling periods was relatively constant over time and between seasons (Figure 5.33a). The proportion of TP : FRP had a mean ratio of approximately 2 : 1 at Bannister Creek and 3 : 1 at Wanneroo. The TP varied from a minimum of 0.049 mg L^{-1} at 12.00 hrs on 24 May 2003 to a maximum of 0.352 mg L^{-1} at 18.00 hrs on 24 August 2002 with a mean (±se) of 0.086 ± 0.004 mg L^{-1}. The TP concentration on 24 August 2002 peaked at 0.352 mg L^{-1} between 17.00 hrs and 19.00 hrs during a rainfall event at the sampling site. At Wanneroo, the TP concentrations of the 24 hour sampling periods were much lower than at Bannister Creek with a mean (±se) of 0.017 ± 0.001 mg L^{-1} ranging from a minimum of 0.015 mg L^{-1} at 13.00 hrs on 1 September 2002 to a maximum of 0.021 mg L^{-1} at 18.00 hrs on 1 September 2002.

At Bannister Creek, the FRP concentrations varied during the 24 hour period and between seasons (Figure 5.33b), ranging from a minimum of 0.026 mg L^{-1} at 20.00 hrs on 22 November 2002 to a maximum of 0.073 mg L^{-1} at 19.00 hrs on 24 August 2002 with a mean (±se) of 0.046 ± 0.001 mg L^{-1}. The FRP concentration on 24 August 2002 between 17.00 hrs and 21.00 hrs peaked more acutely than normal. This was probably caused by a rainfall event at the sampling site. At Wanneroo, FRP concentrations were lower than at Bannister Creek and varied between 0.023 mg L^{-1} at 13.00 hrs (and were relatively constant until 18.00 hrs) on 1 September 2002 and 0.032 mg L^{-1} at 11.00 hrs on 1 September 2002 with a mean (±se) of 0.025 ± 0.001 mg L^{-1}.

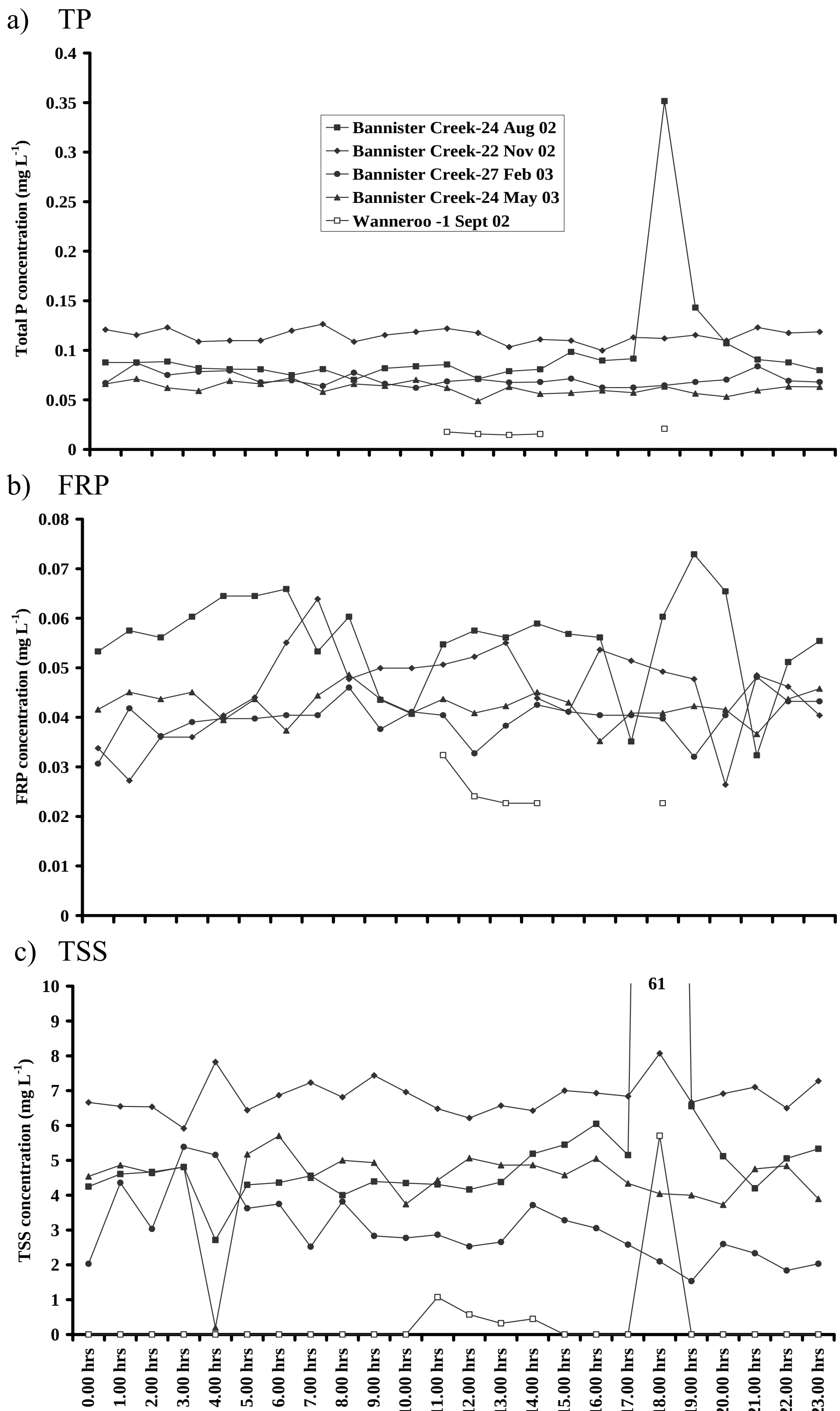


Figure 5.33 Phosphorus and total suspended solid (TSS) concentrations a) TP, b) FRP and c) TSS measured over 24 hour periods at Bannister Creek and Wanneroo.

The TSS concentrations were generally very similar during the 24 hour periods but varied between seasons at Bannister Creek (Figure 5.33c) ranging from a minimum of 0.0002 g L^{-1} at 4.00 hrs on 24 May 2003 to a maximum of 0.061 g L^{-1} at 19.00 hrs on 24 August 2002 with a mean (±se) of 5.313 ± 0.608 g L^{-1}. The TSS concentrations on the 24 August 2002 peaked immediately at 0.006 g L^{-1} between 17.00 hrs and 19.00 hrs, probably due to the rainfall event at this time. At Wanneroo, TSS concentrations were lower than at Bannister Creek ranging from a minimum of below detection in the early morning and at night on 1 September 2002 to a maximum of 0.006 g L^{-1} at 18.00 hrs on 1 September 2002 with a mean (±se) of 0.0003 ± 0.0001 g L^{-1}.

5.3.3 Major Storm Event Samples

The nutrient concentrations found in major storm event samples at Bannister Creek and Wanneroo are shown in Table 5.7.

Table 5.7 Nutrient concentration of major storm event samples at Bannister Creek and Wanneroo

Parameter	TN mg L^{-1}	NH4 mg L^{-1}	NOx mg L^{-1}	TP mg L^{-1}	FRP mg L^{-1}	TSS mg L^{-1}
BANNISTER CREEK						
Range	0.376-0.732	0.039-0.111	0.009-0.163	0.064-0.176	0.020-0.037	6.59-4.13
Mean ± SE	0.516 ± 0.041	0.071 ± 0.008	0.099 ± 0.016	0.115 ± 0.014	0.030 ± 0.002	21.90± 0.004
Median	0.452	0.069	0.107	0.115	0.033	18.6400
WANNEROO						
Range	0.423-1.150	0.219-0.383	0.197-0.777	0.108-0.173	0.086-0.134	13-64.56
Mean ± SE	0.808 ± 0.127	0.315 ± 0.032	0.522 ± 0.112	0.142 ± 0.012	0.110 ± 0.009	37.92 ± 21.79
Median	0.890	0.340	0.589	0.144	0.110	39.0164

5.3.3.1 Nitrogen Concentrations

TN concentrations of major storm event samples at Bannister Creek were virtually unchanged during two events, varying between 0.376 and 0.45 mg L^{-1} on 9 August 2002 and 0.549 and 0.732 mg L^{-1} on 14 September 2002 with a mean (± se) of 0.516 ± 0.041 mg L^{-1} (Figure 5.34a,b). They showed no correlation with discharge ($P > 0.05$; $r = 0.22$ on 9 August 2002 and $r = 0.73$ on 14 September 2002). At Wanneroo, the TN concentrations of major storm event samples declined during the events, ranging between 0.423 mg L^{-1} and 1.15 mg L^{-1} on 11 April 2003 with a mean (± se) of 0.808 ± 0.127 mg L^{-1}. They were not correlated with discharge ($P > 0.05$; $r = 0.62$). The TN concentration at Bannister Creek was less than that recorded at Wanneroo (Figure 5.34c).

At Bannister Creek, NH_4 concentrations of major storm event samples declined along with discharge during the 9 August 2002 storm event and were not correlated with discharge ($P > 0.05$; $r = 0.84$). They were significantly correlated with discharge on 14 August 2002 with a very strong relationship ($P < 0.05$; $r = 0.999$). They varied between 0.039-0.069 mg L^{-1} on 9 August 2002 and 0.071-0.111 mg L^{-1} on 14 September 2002 with a mean (± se) of 0.071 ± 0.008 mg L^{-1} (Figure 5.35ab). At Wanneroo, NH_4 concentrations during a storm event declined with discharge during the storm event from 0.381 to 0.219 mg L^{-1} with a mean (± se) of 0.315 ± 0.032 mg L^{-1} and were not correlated with discharge ($P > 0.05$; $r = 0.64$). NH_4 concentrations of storm event samples at Bannister Creek were lower than at Wanneroo (Figure 5.35c).

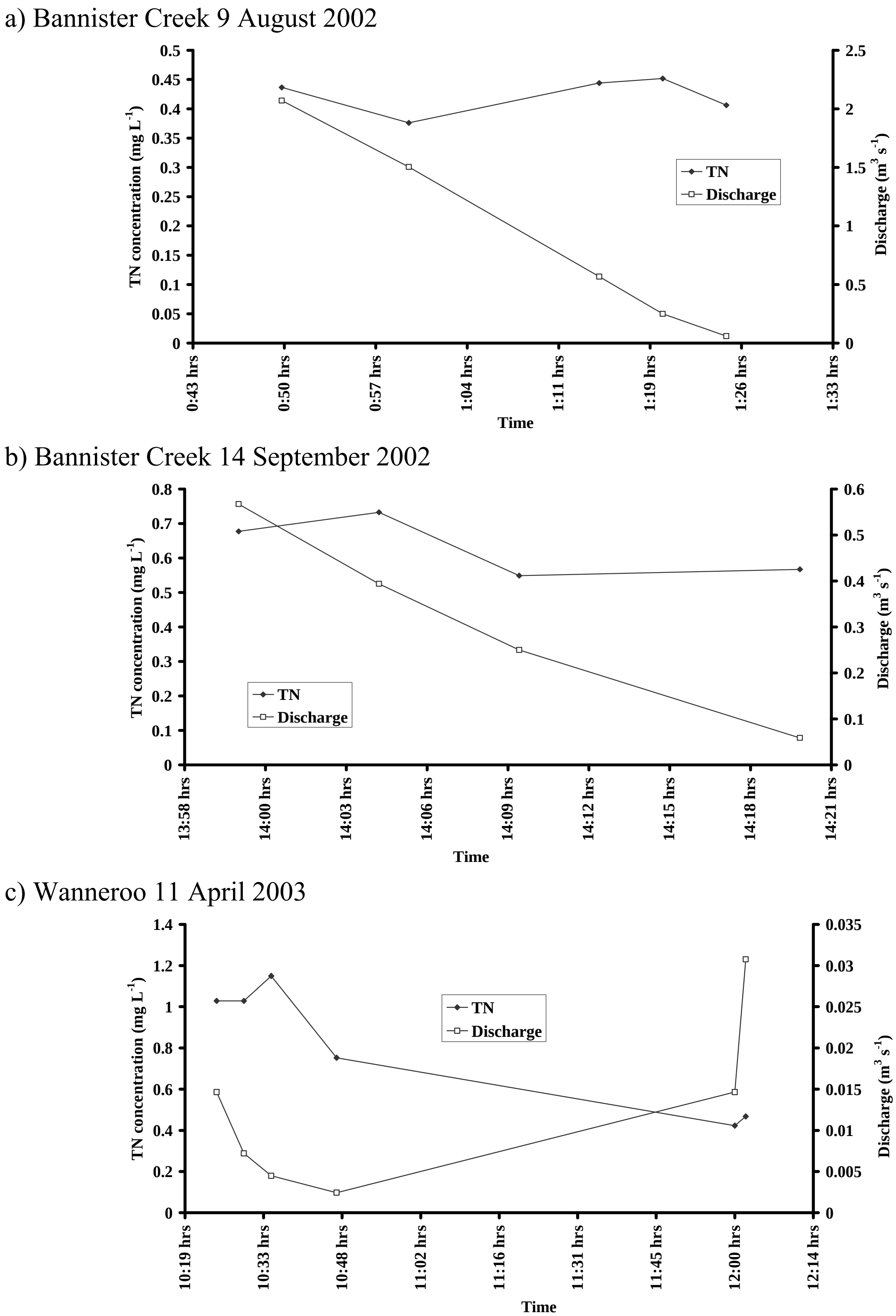
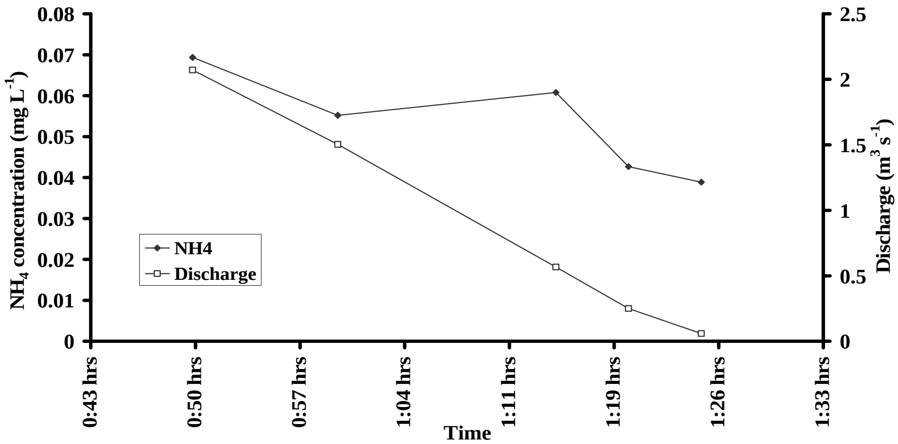
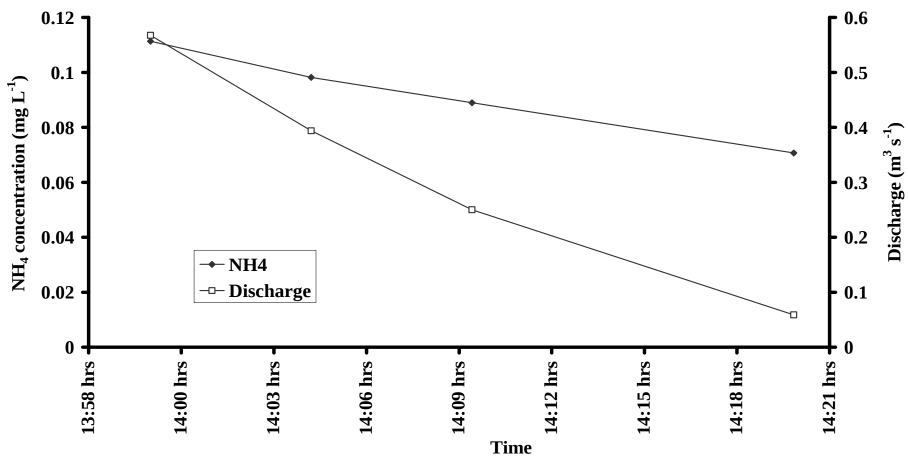


Figure 5.34 Time series of discharge and TN concentration in major storm event captured at a) Bannister Creek on 14 September 2002, b) Bannister Creek on 9 September 2002, and c) Wanneroo on 11 April 2003.

a) Bannister Creek 9 August 2002



b) Bannister Creek 14 September 2002



c) Wanneroo 11 April 2003

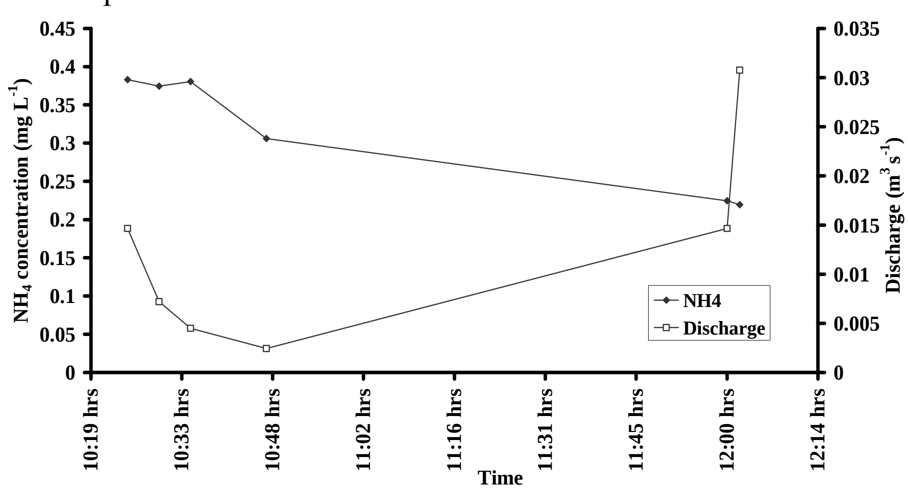
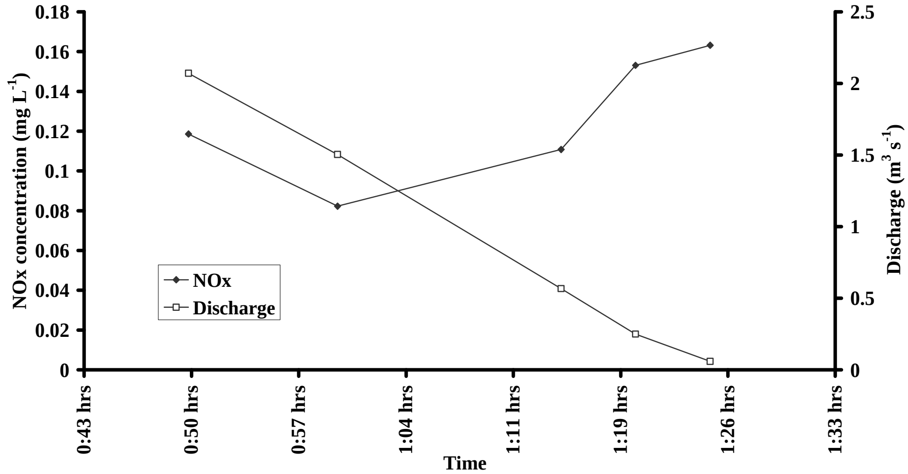
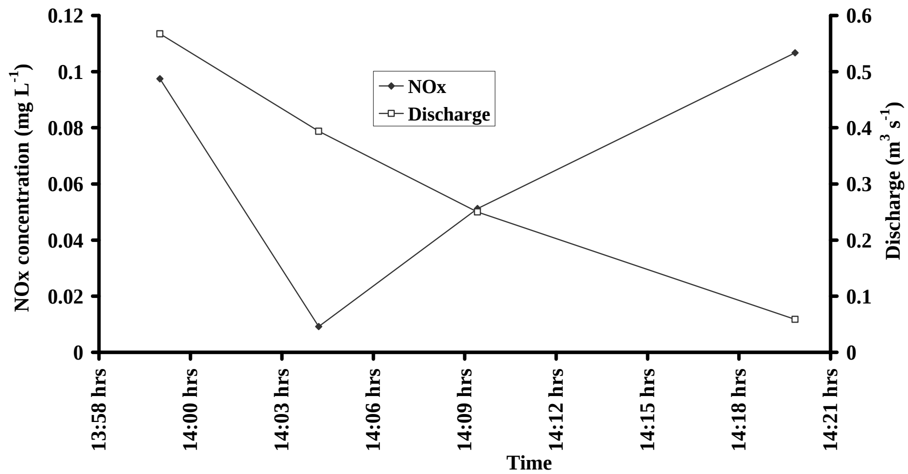


Figure 5.35 Time series of discharge and NH_4 concentration in storm events captured at a) Bannister Creek on 14 September 2002, b) Bannister Creek on 9 September 2002, and c) Wanneroo on 11 April 2003.

a) Bannister Creek 9 August 2002



b) Bannister Creek 14 September 2002



c) Wanneroo 11 April 2003

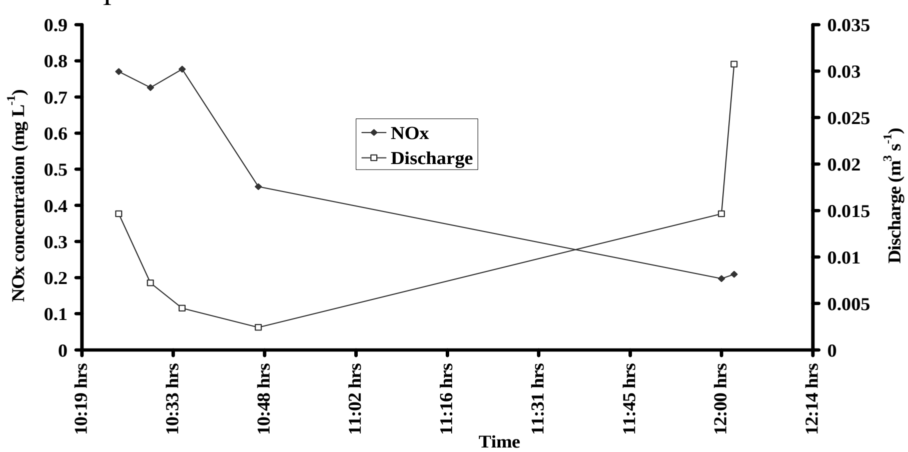


Figure 5.36 Time series of discharge and NOx concentration in storm events captured at a) Bannister Creek on 14 September 2002, b) Bannister Creek on 9 September 2002, and c) Wanneroo on 11 April 2003.

NOx concentrations during the storm events at Bannister Creek on 9 August 2002 and 14 September 2002 showed a similar pattern of decline and recovery while discharge declined. They varied between 0.082 and 0.163 mg L^{-1} on 9 August 2002 and between 0.009 and 0.107 mg L^{-1} on 14 September 2002 with a mean (±se) of 0.099 ± 0.016 mg L^{-1} (Figure 5.36ab). They were not correlated with discharge ($P > 0.05$; $r = 0.7$ on 9 August 2002 and $r = 0.21$ on 14 August 2002). At Wanneroo, they declined slightly from 0.777 to 0.197 mg L^{-1} on 11 April 2003 with a mean (±se) of 0.522 ± 0.112 mg L^{-1} and were not correlated with discharge ($P > 0.05$; $r = 0.58$). NOx concentrations of storm events at Wanneroo were higher than at Bannister Creek (Figure 5.36c).

5.3.3.2 Phosphorus and Total Suspended Solid (TSS) Concentrations

TP concentration during storm events at Bannister Creek showed a slow decline on 9 August 2002, varying between 0.064 and 0.115 mg L^{-1} and was significantly correlated with discharge ($P < 0.05$; $r = 0.99$) (Figure 5.37a). The TP concentration at Bannister Creek on 14 September 2002 was relatively constant during the storm event, varying between 0.130 and 0.176 mg L^{-1} with a mean (±se) of 0.115 ± 0.014 mg L^{-1} (Figure 5.37b) and was not significantly correlated with discharge ($P > 0.05$; $r = 0.89$). At Wanneroo, the TP concentration during the storm event also showed little change (Figure 5.37c), varying between 0.108 and 0.173 mg L^{-1} on 11 April 2003 with a mean (±se) of 0.142 ± 0.012 mg L^{-1}. It was not correlated with discharge ($P > 0.05$; $r = 0.34$).

FRP concentration during storm events showed no real change as discharge declined at both sites (Figure 5.38). At Bannister Creek, it varied between 0.02 and 0.035 mg L^{-1} on 9 August 2002 and 0.031 and 0.037 mg L^{-1} on 14 September 2002 with a mean (± se) of 0.03 ± 0.002 mg L^{-1} and was not correlated with discharge ($P > 0.05$; $r = 0.80$ on 9 August 2002 and $r = 0.64$ on 14 September 2002). At Wanneroo, it varied between 0.086 and 0.134 mg L^{-1} on 11 April 03 with a mean (± se) of 0.110 ± 0.009 mg L^{-1} and was not correlated with discharge ($P > 0.05$; $r = 0.71$). FRP concentration of major storm event samples at Bannister Creek was less than at Wanneroo.

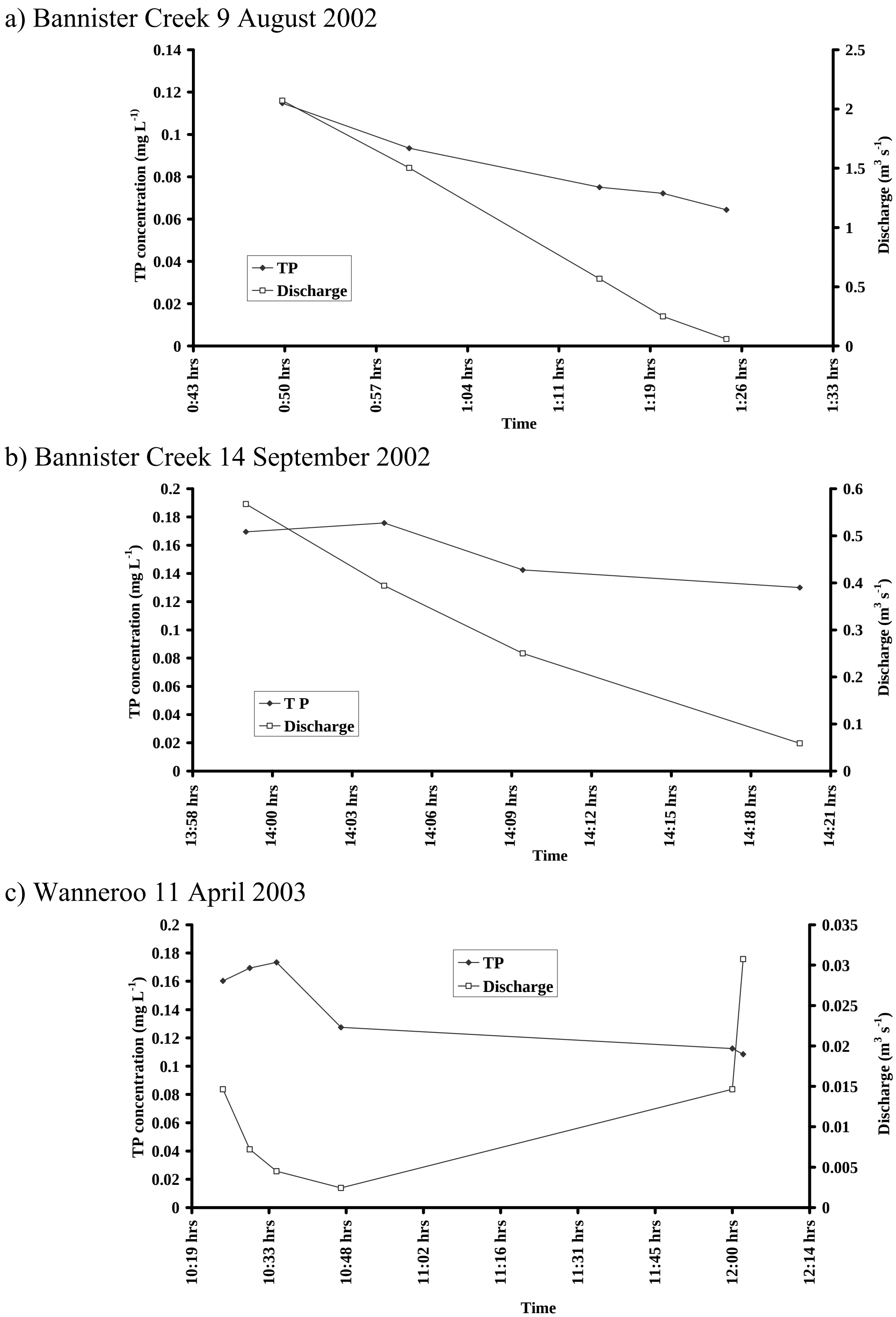
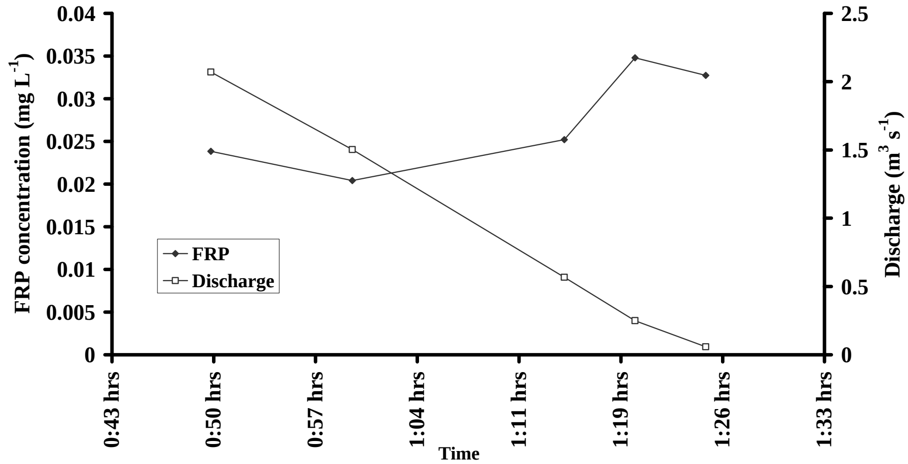
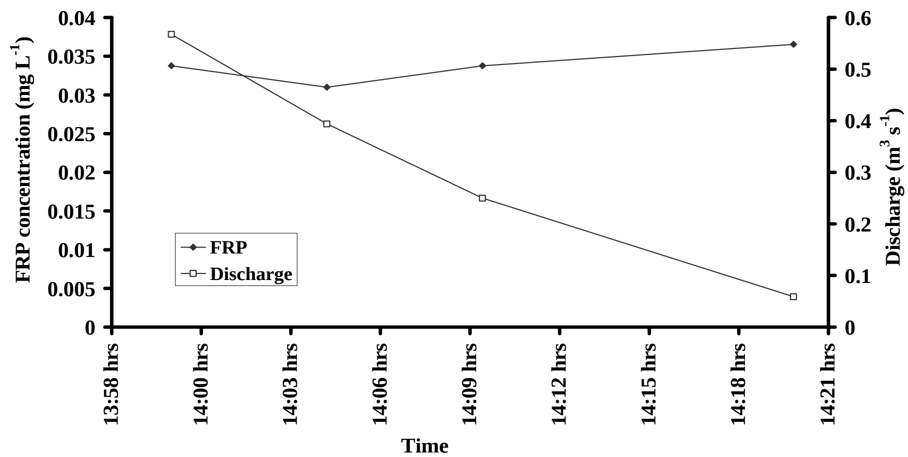


Figure 5.37 Time series of discharge and TP concentration in storm events captured at a) Bannister Creek on 14 September 2002, b) Bannister Creek on 9 September 2002, and c) Wanneroo on 11 April 2003.

a) Bannister Creek 9 August 2002



b) Bannister Creek 14 September 2002



c) Wanneroo 11 April 2003

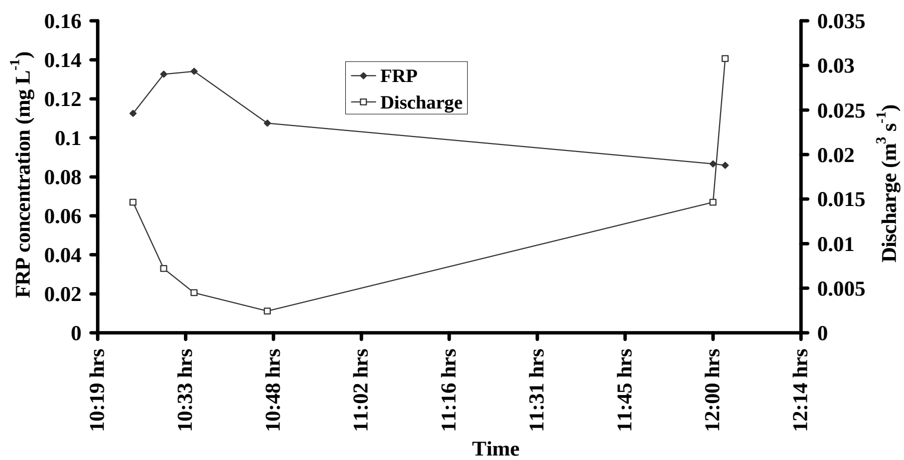
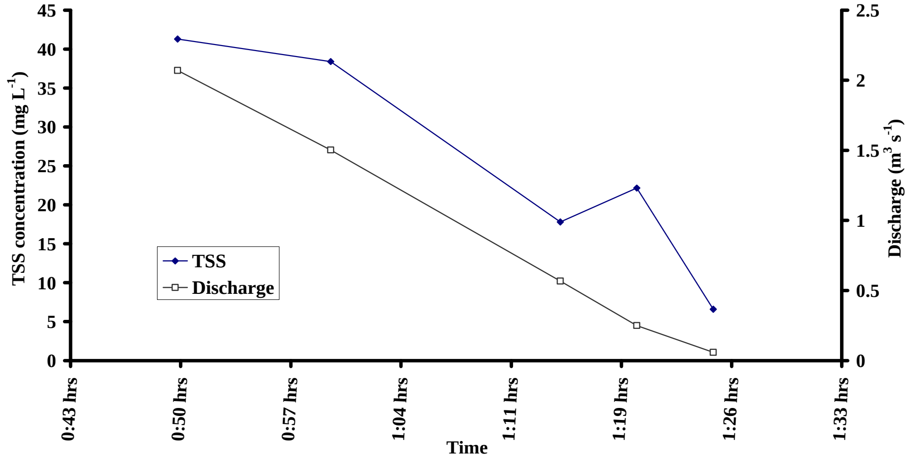
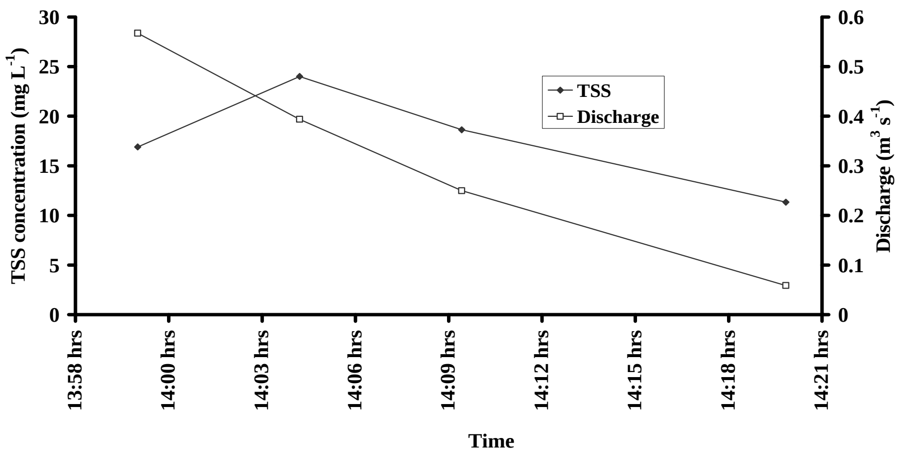


Figure 5.38 Time series of discharge and FRP concentration in storm events captured at a) Bannister Creek on 14 September 2002, b) Bannister Creek on 9 August 2002, and c) Wanneroo on 11 April 2003.

a) Bannister Creek 9 August 2002



b) Bannister Creek 14 September 2002



c) Wanneroo 11 April 2003

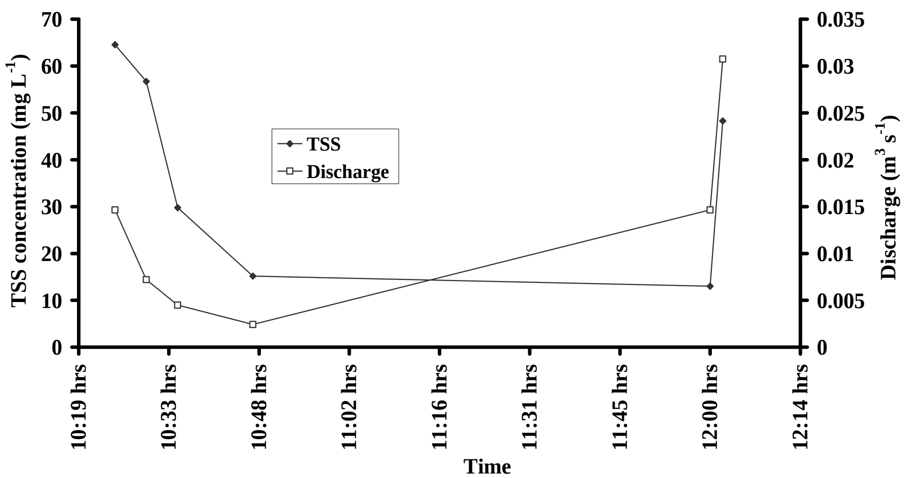


Figure 5.39 Time series of discharge and TSS concentration in storm events captured at a) Bannister Creek on 14 September 2002, b) Bannister Creek on 9 September 2002, and c) Wanneroo 11 April 2003.

At Bannister Creek, the TSS concentrations during storm events declined with discharge during storm events, varying between 6.59 and 41.3 mg L^{-1} on 9 August 2002 and 11.33 and 24 mg L^{-1} on 14 September 2002 with a mean (± se) of 21.90 ± 0.004 mg L^{-1} (Figure 5.39). TSS concentration showed a significant strong relationship with discharge ($P < 0.05$; $r = 0.94$) on 9 August 2002 but no correlation with discharge ($P > 0.05$ and $r = 0.55$) on 14 September 2002. At Wanneroo, TSS concentrations declined over the storm event, varying between 13 and 64.56 mg L^{-1} on 11 April 2003 with mean (± se) of 37.92 ± 21.79 mg L^{-1} and were not correlated with discharge ($P > 0.05$; $r = 0.34$).

5.3.4 Groundwater Samples

The nutrient concentrations of groundwater samples at Bannister Creek and Wanneroo are shown in Table 5.8.

Table 5.8 Nutrient concentration of groundwater samples at Bannister Creek and Wanneroo

Parameter	Oct-02	Nov-02	Dec-02	Jan-03	Feb-03	Mar-03	Apr-03	May-03
BANNISTER CREEK								
Total N mg L^{-1}								
Range	0.766-0.972	0.779-1.046	0.714-1.082	0.647-1.151	0.688-0.932	0.708-0.974	0.657-0.929	0.681-0.973
Mean ± SE	0.845 ± 0.064	0.921 ± 0.078	0.864 ± 0.112	0.837 ± 0.158	0.789 ± 0.073	0.828 ± 0.078	0.750 ± 0.09	0.785 ± 0.094
Median	0.798	0.939	0.797	0.712	0.748	0.803	0.664	0.700
Ammonium (NH_4) mg L^{-1}								
Range	0.617-0.910	0.546-0.736	0.498-0.633	0.443-0.547	0.598-0.668	0.618-0.728	0.522-0.751	0.611-1.02
Mean ± SE	0.747 ± 0.09	0.646 ± 0.05	0.557 ± 0.04	0.539 ± 0.05	0.643 ± 0.02	0.688 ± 0.04	0.661 ± 0.07	0.839 ± 0.12
Median	0.715	0.655	0.541	0.547	0.663	0.717	0.711	0.881
Oxidised Nitrogen (NOx) mg L^{-1}								
Range	0.002	0.002	0.002	0.002	0.0001-0.0035	0.002-0.012	0.002-0.011	0.0007-0.002
Mean ± SE	0.002 ± 0	0.002 ± 0	0.002 ± 0	0.002 ± 0	0.0017 ± 0.001	0.007 ± 0.003	0.006 ± 0.003	0.0016 ± 0.0004
Median	0.002	0.002	0.002	0.002	0.001	0.007	0.005	0.002
Total P mg L^{-1}								
Range	0.01-0.077	0.01-0.093	0.006-0.086	0.01-0.071	0.007-0.071	0.005-0.074	0.006-0.070	0.008-0.072
Mean ± SE	0.035 ± 0.021	0.041 ± 0.026	0.034 ± 0.026	0.032 ± 0.02	0.03 ± 0.021	0.03 ± 0.022	0.028 ± 0.021	0.034 ± 0.02
Median	0.018	0.020	0.011	0.015	0.012	0.009	0.010	0.021
FRP mg L^{-1}								
Range	0.005-0.035	0.005-0.037	0.005-0.038	0.005-0.036	0.006-0.032	0.006-0.032	0.005-0.043	0.005-0.036
Mean ± SE	0.017 ± 0.009	0.017 ± 0.01	0.017 ± 0.01	0.017 ± 0.01	0.016 ± 0.008	0.015 ± 0.009	0.019 ± 0.012	0.016 ± 0.01
Median	0.009	0.008	0.009	0.008	0.011	0.006	0.009	0.008
TSS mg L^{-1}								
Range	0.20-1.875	0.20-4.10	0.20-1.85	0.20-1.05	0.20-0.95	0.20-0.425	0.20-1.20	0.2
Mean ± SE	0.758 ± 0.56	1.625 ± 1.24	0.792 ± 0.53	0.483 ± 0.28	0.45 ± 0.25	0.275 ± 0.08	0.692 ± 0.29	0.2 ± 0
Median	0.200	0.575	0.325	0.200	0.200	0.200	0.675	0.200
WANNEROO								
Total N mg L^{-1}								

Range	0.579-1.48	0.565-1.52	0.553-1.52	0.487-1.42	0.593-1.45	0.468-1.66	0.537-0.569	0.561-1.52
Mean ± SE	0.891 ± 0.297	0.897 ± 0.309	0.904 ± 0.310	0.841 ± 0.291	0.890 ± 0.282	0.889 ± 0.384	0.849 ± 0.296	0.907 ± 0.309
Median	0.610	0.612	0.638	0.617	0.623	0.543	0.569	0.637
Ammonium (NH_4) mg L^{-1}								
Range	0.622-3.27	0.551-2.52	0.520-2.39	0.425-2.42	0.582-2.74	0.572-2.53	0.762-2.11	0.89-3.37
Mean ± SE	1.555 ± 0.86	1.249 ± 0.64	1.15 ± 0.618	1.139 ± 0.642	1.378 ± 0.68	1.245 ± 0.64	1.228 ± 0.441	1.770 ± 0.80
Median	0.771	0.675	0.544	0.572	0.815	0.639	0.812	1.050
Oxidised Nitrogen (NOx) mg L^{-1}								
Range	0.0007-0.002	0.002-0.012	0.002	0.002	0.0015-0.031	0.005-0.046	0.0008-0.042	0.002-0.023
Mean ± SE	0.0016 ± 0.0004	0.006 ± 0.003	0.002 ± 0	0.002 ± 0	0.011 ± 0.01	0.019 ± 0.014	0.016 ± 0.013	0.009 ± 0.007
Median	0.002	0.003668262	0.002	0.002	0.001466667	0.005466667	0.004790065	0.002
Total P mg L^{-1}								
Range	0.005-0.019	0.008-0.022	0.010-0.022	0.012 ± 0.023	0.013-0.019	0.009-0.031	0.006-0.015	0.008-0.016
Mean ± SE	0.013 ± 0.004	0.015 ± 0.004	0.015 ± 0.004	0.018 ± 0.003	0.015 ± 0.002	0.017 ± 0.008	0.009 ± 0.003	0.012 ± 0.002
Median	0.015	0.015	0.011	0.019	0.013	0.013	0.007	0.011
FRP mg L^{-1}								
Range	0-0.007	0.004-0.011	0.004-0.013	0.007-0.041	0.004-0.006	0.002-0.009	0.002-0.013	0.004 ± 0.02
Mean ± SE	0.004 ± 0.002	0.007 ± 0.002	0.007 ± 0.003	0.018 ± 0.011	0.005 ± 0.0005	0.006 ± 0.002	0.008 ± 0.003	0.01 ± 0.005
Median	0.006028875	0.005346282	0.005170068	0.007210884	0.00429702	0.007878726	0.00675406	0.00675406
TSS mg L^{-1}								
Range	0.2	0.2-.0.5	0.2	0.2	0.2	0.2	0.2	0.2
Mean ± SE	0.2 ± 0.2	0.30 ± 0.2	0.2 ± 0	0.2 ± 0	0.2 ± 0	0.2 ± 0	0.2 ± 0	0.2 ± 0
Median	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200

5.3.4.1 Nitrogen Concentrations

At both sites, the TN concentration of groundwater samples varied between 0.75 and 0.921 mg L^{-1} (Figure 5.40a). At Bannister Creek, the TN concentrations of groundwater samples varied from a minimum of 0.647 mg L^{-1} in the Glencairn bore on January 2003 to a maximum of 1.151 mg L^{-1} in the Ritson bore on January 2003 with a mean (± se) of 0.827 ± 0.031 mg L^{-1}. At Wanneroo, the TN concentrations of groundwater samples varied from a minimum of 0.468 mg L^{-1} in the Towarda bore on March 2003 to a maximum of 1.657 mg L^{-1} in the Mundaree bore on March 2003 with a mean (± se) of 0.884 ± 0.031 mg L^{-1}. TN concentrations at Wanneroo were slightly higher than those at Bannister Creek. As TN concentrations at Bannister Creek were smaller than the sum of NH_4 and NOx this indicates that the chemical analysis may have achieved only poor recoveries of TN. Therefore caution should be exercised when interpreting these results.

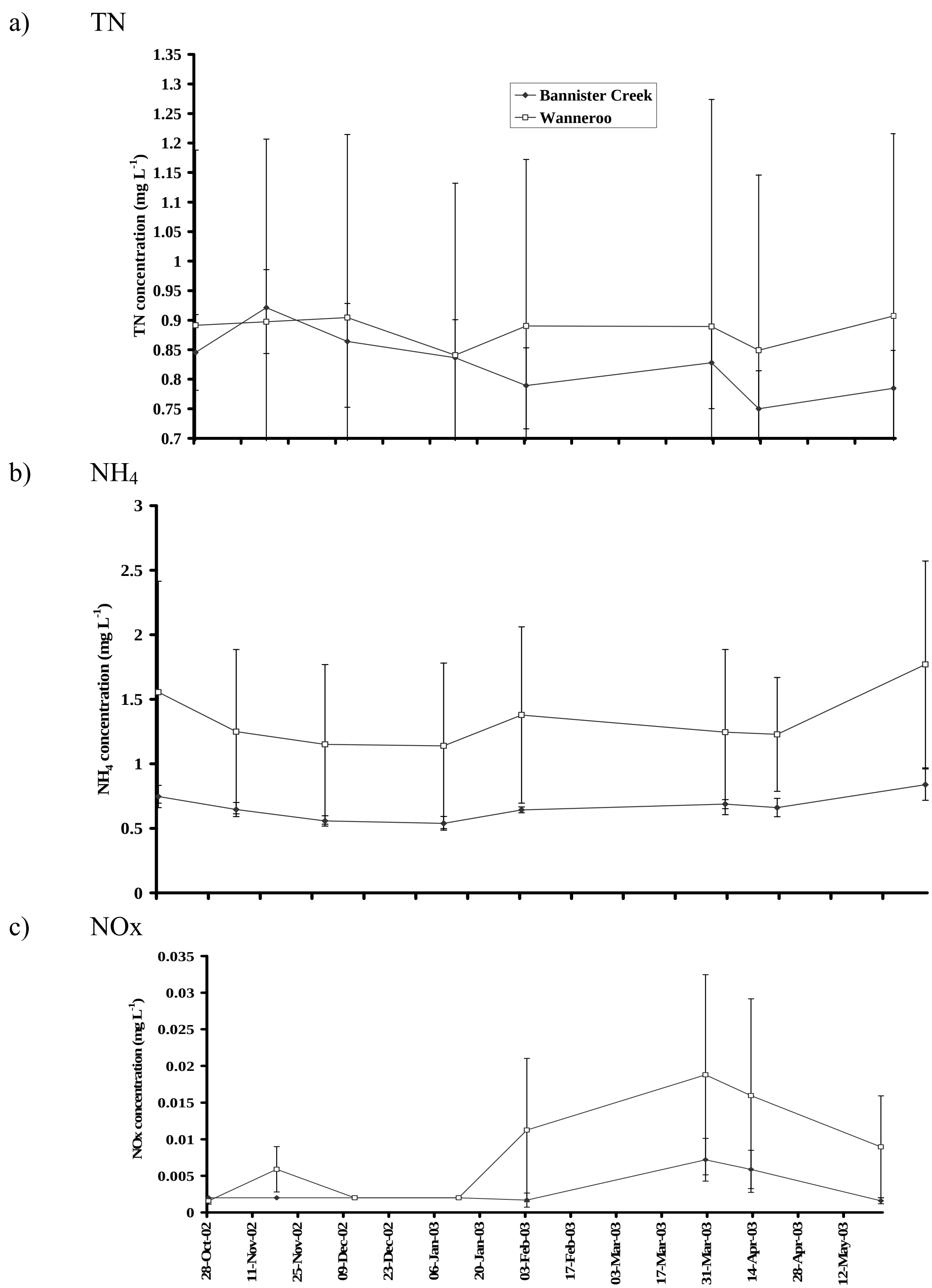


Figure 5.40 Mean monthly nitrogen concentrations a) Total N, b) NH_4, and c) NOx of groundwater measured at Bannister Creek and Wanneroo between October 2002 and May 2003.

The NH_4 concentrations of groundwater samples at both sites varied between 0.60 and 1.80 mg L^{-1} and were generally constant at both sites (Figure 5.40b). At Bannister Creek, the NH_4 concentrations of groundwater samples varied from a minimum of 0.443 mg L^{-1} in the Keslake bore on January 2003 to a maximum of 1.025 mg L^{-1} in the Glencairn bore on May 2003 with a mean (± se) of 0.665 ± 0.027 mg L^{-1}. At Wanneroo, the NH_4 concentrations of groundwater samples varied from a minimum of 0.425 mg L^{-1} in the Towarda bore on January 2003 to a maximum of 3.371 mg L^{-1} in the Mundaree bore on May 2003 with a mean (± se) of 1.339 ± 0.204 mg L^{-1}. The NH_4 concentration of groundwater samples at Bannister Creek was less than that recorded at Wanneroo.

The NOx concentrations of groundwater samples were very low in winter but increased in concentration in summer at both sites ranging between 0.002 mg L^{-1} and 0.018 mg L^{-1} (Figure 5.40c). At Bannister Creek, the NOx concentrations of groundwater samples in every bore were < 0.002 mg L^{-1} from October 2002 to February 2003. The rest of the NOx concentrations of the groundwater samples varied between < 0.002 mg L^{-1} to 0.008 mg L^{-1} with a mean (± se) of 0.003 ± 0.001. At Wanneroo, the NOx concentrations of groundwater samples varied from a minimum of < 0.002 mg L^{-1} in every bore on December 2002 and January 2003 to a maximum of 0.046 mg L^{-1} in the Mega bore on March 2003 with a mean (± se) of 0.009 ± 0.003 mg L^{-1}. The NOx concentration of groundwater samples at Bannister Creek were lower than those recorded at Wanneroo.

5.3.4.2 Phosphorus and Total Suspended Solid (TSS) Concentrations

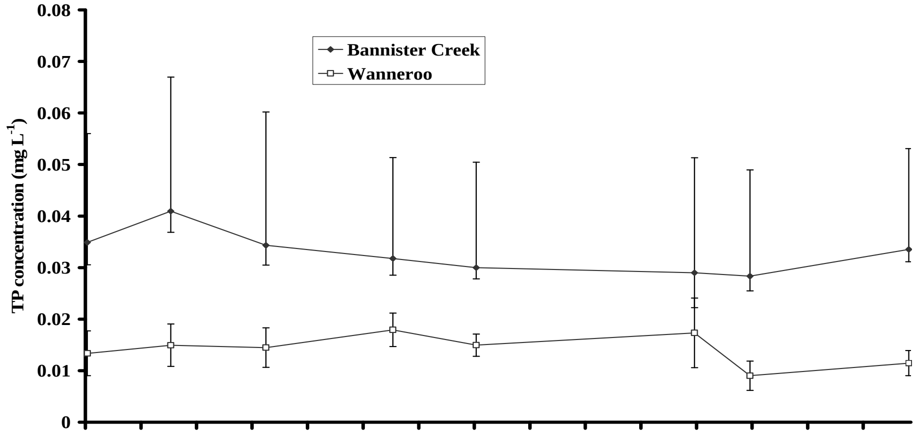
At both sites, the TP concentrations of groundwater samples were relatively constant varying between 0.01 to 0.04 mg L^{-1} (Figure 5.41a). At Bannister Creek, the TP concentrations of groundwater samples varied from a minimum of 0.005 mg L^{-1} in the Ritson bore on March 2003 to a maximum of 0.093 mg L^{-1} in the Glencairn bore on November 2002 with an mean (± se) of 0.033 ± 0.007 mg L^{-1}. At Wanneroo site, the TP concentrations of groundwater samples varied from a minimum of 0.005 mg L^{-1} in the Towarda bore on October 2002 to a maximum of 0.031 mg L^{-1} in the Mega bore on March

2003 with an mean (± se) of 0.014 ± 0.001 mg L^{-1}. The TP concentration of groundwater samples at Bannister Creek was higher than those recorded at Wanneroo.

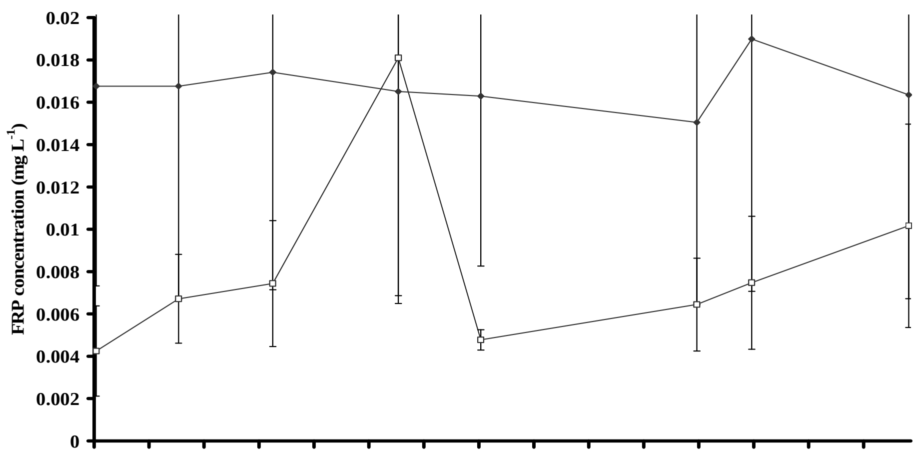
At both sites, the FRP concentrations of groundwater samples were relatively constant between 0.004 and 0.02 mg L^{-1} except for the FRP concentration at Wanneroo on January 2003 which peaked at 0.018 mg L^{-1} (Figure 5.41b). At Bannister Creek, the FRP concentrations of groundwater varied from a minimum of 0.005 mg L^{-1} in the Ritson bore on December 2002 to a maximum of 0.043 mg L^{-1} in the Glencairn bore on April 2003 with a mean (± se) of 0.017 ± 0.003 mg L^{-1}. At Wanneroo, the FRP concentrations of groundwater samples varied from a minimum of 0.002 mg L^{-1} in the Towarda bore on March 2003 to a maximum of 0.041 mg L^{-1} in the Mundaree bore on January 2003 with a mean (± se) of 0.008 ± 0.002 mg L^{-1}. The FRP concentration of groundwater samples at Bannister Creek was higher than those recorded at Wanneroo.

At both sites, most TSS concentrations were very low, fluctuating between 0.2 mg L^{-1} and 1.80 mg L^{-1} (Figure 5.41c). At Bannister Creek, most groundwater samples (14 samples out of 24 samples) had very low TSS concentrations (< 0.20 mg L^{-1}). The rest (10 samples) varied from < 0.20 mg L^{-1} to 4 mg L^{-1}. At Wanneroo, most groundwater samples had very low TSS concentrations of < 0.20 mg L^{-1}. TSS concentrations in every bore on October 2002 and from January 2003 to April 2003 were < 0.20 mg L^{-1}.

a) TP



b) FRP



c) TSS

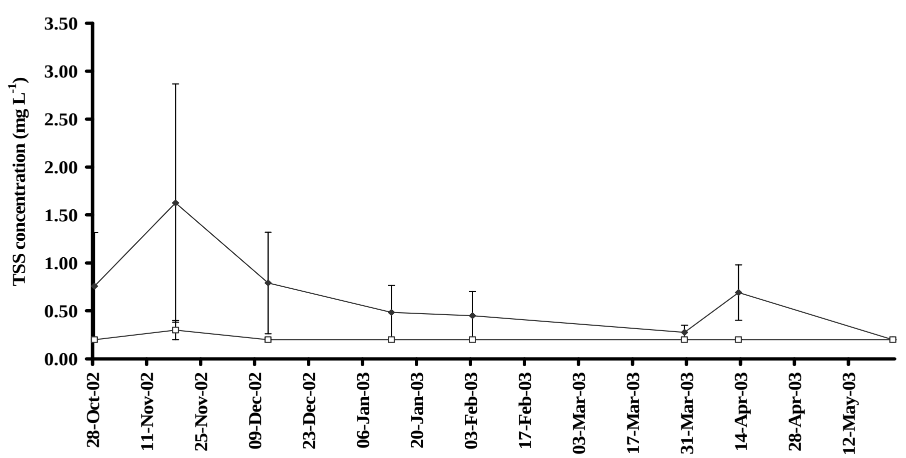


Figure 5.41 Mean monthly phosphorus concentrations a) TP, b) FRP, and mean monthly total suspended solid concentration c) TSS of groundwater measured at Bannister Creek and Wanneroo between October 2002 and May 2003.

5.4 Nutrient Load

The nutrient load discharged from each catchment depended on the volume of stormwater discharged and the nutrient concentration.

5.4.1 Daily Nutrient Load

The daily nutrient loads found in stormwater at Bannister Creek and Wanneroo are shown in Table 5.9.

Table 5.9 Daily nutrient output loads at Bannister Creek and Wanneroo

Parameter	TN (g)	NH4 (g)	NOx (g)	TP (g)	FRP (g)	TSS (g)
BANNISTER CREEK						
Range	0-63464	0-1795	0-21367	0-4754	0-4272	0-969,102
Mean ± SE	962.22 ± 225.71	55.61 ± 7.28	403.69 ± 91.57	75.84 ± 17.17	49.65 ± 14.73	8,469.11 ± 33,10.36
Median	32.92	9.31	12.51	1.85	0.27	0.00
WANNEROO						
Range	2.26-785.80	0.22-292.67	0.02-588.33	0.20-190.06	0.09-147.92	2.09-49,314.20
Mean ± SE	89.3 ± 13.17	19.93 ± 4.07	25.59 ± 7.07	15.31 ± 2.92	8.63 ± 2.10	2113.15 ± 572.95
Median	51.57	6.56	7.03	6.56	2.63	549.46

5.4.1.1 Nitrogen Load

At both sites, TN loads discharged from the drain were greatly variable (Figure 5.42a). At Bannister Creek, the TN loads discharged ranged from a minimum of 0 g d^{-1} on 11 August 2002 to a maximum of 63.5 kg d^{-1} on 4 June 2002 with a mean (± se) of 962 ± 225.71 g d^{-1}. At Wanneroo, the TN loads discharged ranged from a minimum of load 2 g d^{-1} on 8 December 2002 to a maximum of 786 g d^{-1} on 12 April 2003 with a mean (± se) of 89.3 ± 13.17 g d^{-1}. The TN load at Bannister Creek was higher than recorded at Wanneroo.

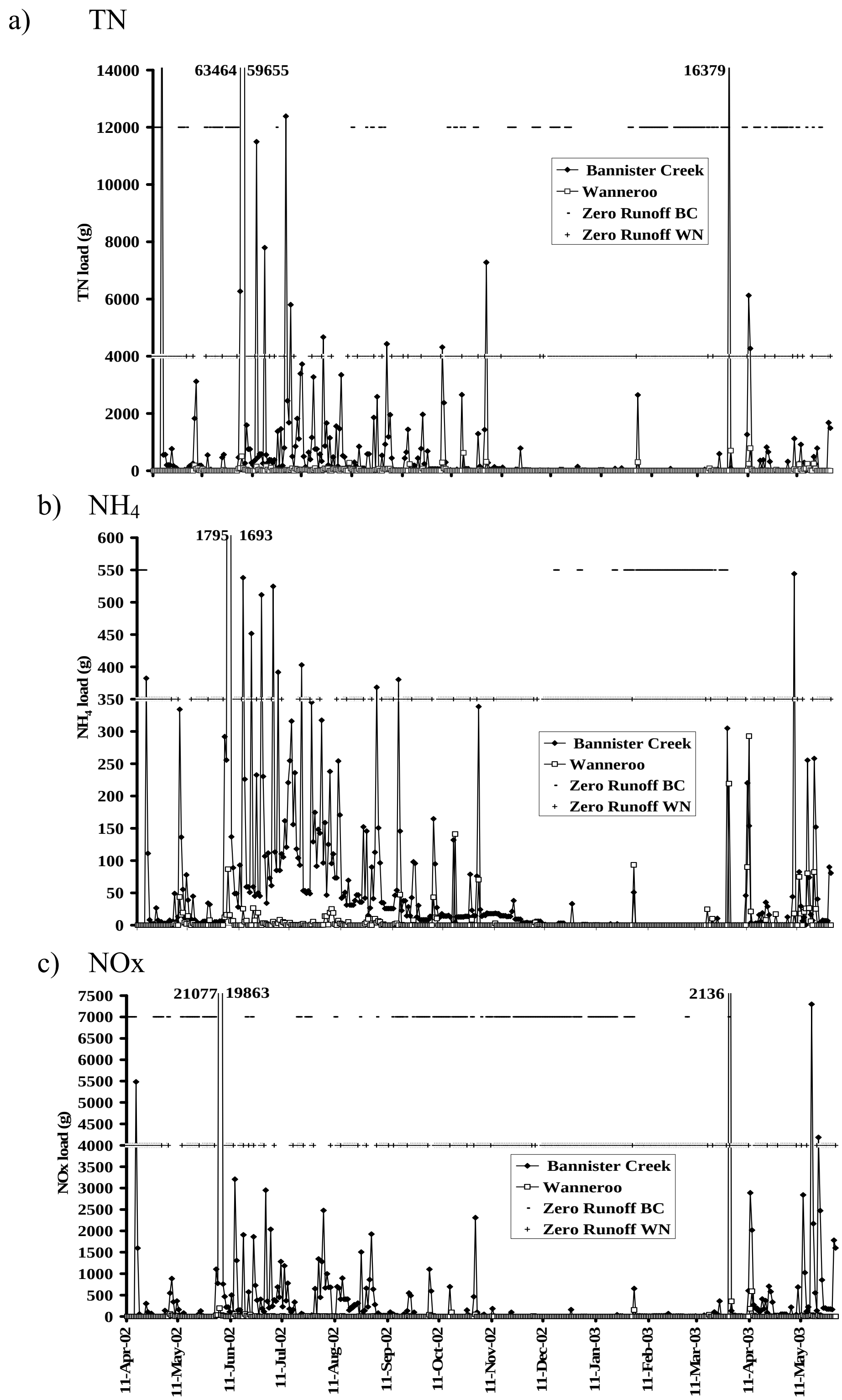


Figure 5.42 Daily nitrogen loads a) TN, b) NH_4 and c) NOx estimated at Bannister Creek and Wanneroo between April 2002 and May 2003 (The Zero runoff lines indicate days where was no stormwater runoff discharged from a catchment drain).

At both sites, the NH_4 loads discharged from the drain were highly variable (Figure 5.42b). At Bannister Creek, the NH_4 loads discharged ranged from a minimum of 0 g d^{-1} to a maximum of 1.8 kg d^{-1} on 24 June 2002 with a mean (± se) of 55.61 ± 7.28 g d^{-1}. At Wanneroo, the NH_4 loads discharged ranged from a minimum of 0 g d^{-1} to a maximum of 293 g d^{-1} on 12 April 2003 with a mean (± se) of 19.93 ± 4.07 g d^{-1}. The NH_4 load at Bannister Creek was higher than recorded at Wanneroo.

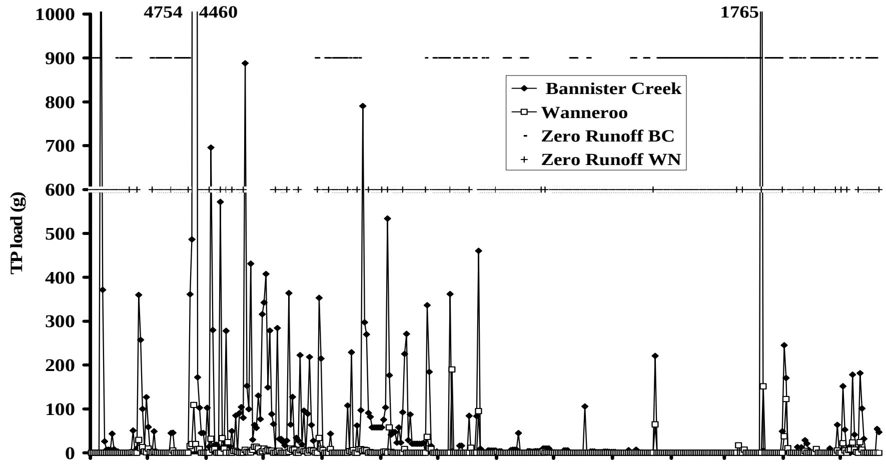
At both sites, the NOx loads discharged from the drain were highly variable (Figure 5.42c). At Bannister Creek, the NOx loads discharged ranged from a minimum of 0 g d-1 to a maximum of 21.37 kg d-1 on 30 March 2003 with a mean (± se) of 403.69 ± 91.57 g d-1. At Wanneroo, the NOx loads discharged ranged from a minimum of 0 g d-1 to a maximum of 588 g d-1 on 12 April 2003 with a mean (± se) of 25.59 ± 7.07 g d-1.The NOx load at Bannister Creek was higher than that recorded at Wanneroo.

5.4.1.2 Phosphorus and Total Suspended Solid Load

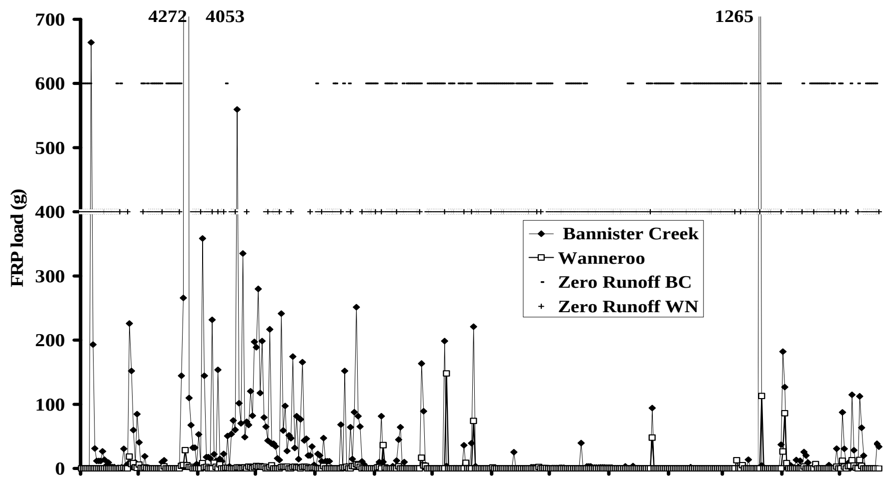
At both sites, the TP loads discharged from the drain were highly variable (Figure 5.43a). At Bannister Creek, the TP loads discharged ranged from a minimum of 0 g d^{-1} to a maximum of 4.8 kg d^{-1} on 30 March 2003 with a mean (± se) of 75.84 ± 17.71 g d^{-1}. At Wanneroo, the TP loads discharged ranged from a minimum of 0 g d^{-1} to a maximum of 190 g d^{-1} on 18 October 2002 with a mean (± se) of 15.31 ± 2.92 g d^{-1}. The TP load at Bannister Creek was higher than that recorded at Wanneroo.

At both sites, the FRP loads discharged from the drain were highly variable (Figure 5.43b). At Bannister Creek, the FRP loads discharged ranged from a minimum of 0 g d^{-1} to a maximum of 4.3 kg d^{-1} on 4 June 2002 with a mean (± se) of 49.65 ± 14.73 g d^{-1}. At Wanneroo, the FRP loads discharged ranged from a minimum of 0 g d^{-1} to a maximum of 148 g d^{-1} on 18 October 2002 with a mean (± se) of 8.63 ± 2.10 g d^{-1}. The FRP load at Bannister Creek was higher than that recorded at Wanneroo.

a) TP



b) FRP



c) TSS

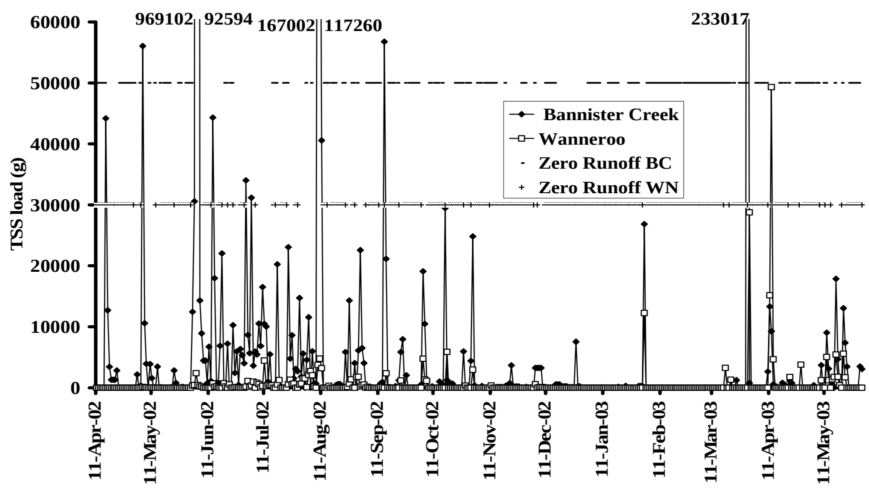


Figure 5.43 Daily phosphorus loads a) TP, and b) FRP and total suspended solid (TSS) loads c) TSS at Bannister Creek and Wanneroo between April 2002 and May 2003 (The Zero runoff lines indicate days where was no stormwater runoff discharged from a catchment drain).

At both sites the TSS loads discharged from the drain were highly variable (Figure 5.43c). At Bannister Creek, the TSS loads discharged ranged from a minimum of 0 g d^{-1} to a maximum of 969 kg d^{-1} on 4 June 2002 with a mean (± se) of 8.47 ± 33 kg d^{-1}. At Wanneroo, the TSS loads discharged ranged from a minimum of 2 g d^{-1} to a maximum of 49 kg d^{-1} on 12 April 2003 with a mean (± se) of 2.11 ± 0.57 g d^{-1}. The TSS load at Bannister Creek was higher than that recorded at Wanneroo.

5.4.2 Monthly and Annual Nutrient Load

The monthly nutrient loads found in stormwater only at the Bannister Creek and Wanneroo sites are shown in Table 5.10.

Table 5.10 Monthly and annual nutrient output loads from the drains at Bannister Creek and Wanneroo

Month	TN (kg)		NH_4 (kg)		NOx (kg)		TP (kg)		FRP (kg)		TSS (kg)	
	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN
May-02	12.11	0.49	0.93	0.12	2.75	0.16	1.12	0.08	0.66	0.05	85.94	0.32
Jun-02	178.08	1.40	7.46	0.24	56.24	0.54	12.92	0.30	10.31	0.08	2113.55	6.69
Jul-02	65.70	1.05	5.30	0.04	13.11	0.08	4.86	0.12	3.72	0.05	236.29	16.51
Aug-02	16.75	0.99	2.51	0.15	17.39	0.09	1.60	0.11	1.04	0.03	385.94	27.84
Sep-02	19.47	0.55	1.93	0.08	4.53	0.05	3.79	0.09	0.66	0.06	130.01	5.06
Oct-02	13.13	1.10	0.89	0.22	3.04	0.16	1.16	0.26	0.54	0.18	76.07	13.46
Nov-02	9.34	0.32	0.76	0.07	2.74	0.05	0.59	0.10	0.25	0.08	32.08	3.32
Dec-02	1.68	0.02	0.09	0.01	0.16	0.01	0.19	0.00	0.06	0.00	24.04	0.84
Jan-03	0.50		0.01		0.10		0.05		0.03		1.26	
Feb-03	2.72	0.30	0.05	0.09	1.03	0.15	0.22	0.06	0.10	0.05	27.14	12.25
Mar-03	17.31	0.81	0.32	0.25	22.17	0.41	1.80	0.18	1.29	0.13	235.26	33.32
Apr-03	14.30	1.13	0.56	0.43	9.45	0.81	0.55	0.18	0.45	0.13	29.19	74.66
May-03	22.45	1.13	1.75	0.38	27.49	0.13	0.93	0.11	0.58	0.06	70.59	25.50
Yearly total load	373.55	9.29	22.57	2.07	160.20	2.65	29.79	1.59	19.67	0.90	3447.34	219.77

5.4.2.1 Nitrogen Load

At Bannister Creek, the TN loads were high during the winter months (June, July and August) and low during the summer months (December to February). The loads discharged from the drain were highly variable, ranging from a minimum of 0.48 kg month^{-1} in January 2003 to a maximum of 178 kg month^{-1} in June 2002, with a mean (± se) of 28.37 ± 0.35 kg month^{-1}. However the TN loads discharged from the drain at Wanneroo were generally consistent, ranging between 0.02 kg month^{-1} in December 2002 and 1.4 kg month^{-1} in June 2002 with a mean (± se) of 0.77 ± 0.12 kg month^{-1}. The TN load at Bannister Creek was higher than that recorded at Wanneroo.

At Bannister Creek, the NH_4 loads discharged from the drain were high during the winter months (June, July and August) and low during the summer months (December to February), ranging from a minimum of 0.01 kg month^{-1} in January 2003 to a maximum of 7.46 kg month^{-1} in July 2002, with a mean (± se) of 1.74 ± 0.02 kg month^{-1}. At Wanneroo, the NH_4 loads discharged ranged from a minimum of 0.006 kg month^{-1} in December 2002 to a maximum of 0.429 kg month^{-1} in April 2003 with a mean (± se) of 0.17 ± 0.04 kg month^{-1}. The NH_4 load at Bannister Creek was higher than that recorded at Wanneroo.

At Bannister Creek, the NOx loads discharged from the drain were high during the winter months (June, July and August) and low during the summer months (December to February). At Bannister Creek, the NOx loads discharged ranged from a minimum of 0 kg month^{-1} in December 2002 and January 2003 to a maximum of 56 kg month^{-1} in August 2002 with a mean (± se) of 12.32 ± 0.12 kg month^{-1}. At Wanneroo, the NOx loads were very low and generally consistent, ranging from a minimum of 0.01 kg month^{-1} in December 2002 to a maximum of 0.813 kg month^{-1} in April 2003 with a mean (± se) of 0.22 ± 0.07 kg month^{-1}. The NOx load at Bannister Creek was higher than that recorded at Wanneroo.

5.4.2.2 Phosphorus and Total Suspended Solid Load

At Bannister Creek, the TP loads discharged from the drain were high during the winter months (June, July and August) and low during the summer months (December to February). The TP loads discharged ranged from a minimum of 0.05 kg month^{-1} in January 2003 to a maximum of 12.92 kg month^{-1} in June 2002 with a mean (± se) of 2.29 ± 0.03 kg month^{-1}. At Wanneroo, the TP loads were generally consistent. They ranged from a minimum of 0.004 kg month^{-1} in December 2002 to a maximum of 0.304 kg month^{-1} in June 2002 with a mean (± se) of 0.13 ± 0.02 kg month^{-1}. The TP load at Bannister Creek was higher than that recorded at Wanneroo.

At Bannister Creek, the FRP loads discharged from the drain were high during the winter months (June, July and August) and low during the summer months (December to February). At Bannister Creek, the FRP loads discharged ranged from a minimum of 0.031 kg month^{-1} in January 2003 to a maximum of 10.31 kg month^{-1} in July 2002 with a mean (± se) of 1.51 ± 0.02 kg month^{-1}. At Wanneroo, the FRP loads were very low and generally consistent. They ranged from a minimum of 0 kg month^{-1} in December 2002 and January 2003 to a maximum of 0.18 kg month^{-1} in October 2002 with a mean (± se) of 0.07 ± 0.01 kg month^{-1}.The FRP load at Bannister Creek was higher than that recorded at Wanneroo.

At Bannister Creek, the TSS loads discharged from the drain were high during the winter months (June, July and August) and low during the summer months (December to February). At Bannister Creek, the TSS loads discharged ranged from a minimum of 1.26 kg month^{-1} in January 2003 to a maximum of 2114 kg month^{-1} in June 2002 with a mean (± se) of 265.18 ± 4.17 kg month^{-1}. At Wanneroo, the TSS loads were very low and consistent. They ranged from a minimum of 0 kg month^{-1} in January 2003 to a maximum of 74.656 kg month^{-1} in April 2003 with a mean (± se) of 18.06 ± 6.08 kg month^{-1}. The TSS load at Bannister Creek was higher than that recorded at Wanneroo.

5.4.3 Accuracy of Nutrient Load Estimation

The accuracy of the load estimations for nutrients can be assessed by examining the 24 hour sampling periods to determine how much the nutrient concentration of the samples collected at a regular time deviated from the range of nutrient concentrations experienced over 24 hours. By comparing the nutrient concentration of a sample collected at the regular sampling time to the minimum and maximum nutrient concentrations measured during the 24 hours, an indication of the potential uncertainty in nutrient load estimation could be achieved (Table 5.11).

Table 5.11 The percentage that daily nutrient loads could have been over-estimated or under-estimated by using fixed sampling times compared to minimal and maximal nutrient concentrations recorded over 24 hours

Season	TN	NH_4	NOx	TP	FRP	TSS
% OVER ESTIMATED						
24-Aug-02	42	43	76	22	42	55
22-Nov-02	22	21	41	0	51	15
27-Feb-02	16	39	39	1	24	50
24-May-03	25	30	50	18	0	96
% Mean	26	33	51	10	29	54
% UNDER ESTIMATED						
24-Aug-02	51	50	0	74	23	90
22-Nov-02	0	11	25	21	16	14
27-Feb-02	8	53	7	28	16	43
24-May-03	6	5	0	18	28	11
% Mean	16	30	8	35	21	40

Table 5.11, reveals an average overestimation of nutrient concentrations for four seasons of 10% for TP, 51% for NOx, 26% for TN, 33% for NH_4, 29% for FRP and around 54% for TSS. Nutrient loads were more likely to be overestimated than underestimated except for TP and NH_4.

CHAPTER 6 NUTRIENT BALANCE AND MANAGEMENT

This chapter aims to assess the nutrient balance at each study site by assuming that total nutrient output loads from drain minus total nutrient input loads from rainwater source via hard surface area of the catchment equals total nutrient input loads from non-point sources. By this assumption the sources of input nutrient loads can be divided into two sources. One comes from point sources and the other come from non point sources. In this study case point sources can be identified as rainwater sources and non point sources can be identified as a combination of all kinds of human activities (eg fertilizer application, ground water usage, vehicle emission, pet waste and carwash). Then given examples of unawareness in human activities of carelessness in their routine life style behaviours were highlighted to show how important of small carelessness in our routine life style can make a great contribution of nutrient output load from the drain in the catchment at the study areas. Ultimately catchment management approaches were recommended to reduce nutrient discharge from stormwater in these catchment types to achieve options for improved management.

6.1 Nutrient Balance

The potential pathways that nutrients and sediments can follow from input sources to discharge from the catchment are important in identifying potential catchment management or treatment systems to reduce nutrients being discharged to receiving environments. A mass balance of nutrients entering the catchment and leaving it in the discharge will highlight some of these pathways. This nutrient mass balance study will apply a realistic and straightforward method to analyse the nutrient balance by focusing only on the portion of impervious areas associated with transport-related functions (such as roads, driveways, footpaths etc.) of the catchment. This is due to house runoff being contained on individual properties in the studied catchments, research by Schueler (1987) showing that as much as 70% of the impervious area is associated with transport-related functions.

Nutrient balance is the difference between nutrient input load entering the catchment and nutrient output load being discharged from the catchment. In this study, we can be relatively certain that the majority of rainwater on hard surface areas will enter the discharge. The remaining nutrient input loads come from different sources such as fertiliser application; vehicle usage, groundwater usage for watering lawns gardens and pot plants; pet waste disposal; and car washing. All these sources are classified as non-point sources in this study because the pathway from source to discharge is not known (see more details in Appendix 5 Nutrient Balance / Mass Balance of Nutrients).

6.1.1 Total Nitrogen Nutrient Balance

TN nutrient balance and TN proportion from rainwater and non-point sources at Bannister Creek are shown in Table 6.1 and Figure 6.1 respectively. The estimation of the quantity of TN from rain water included a proportion of NOx gases released from vehicle transport, assuming that these NOx gases are dissolved in rainwater as a wet deposition from the atmospheric fallout. The quantity of TN from rain varied from a minimum of 0.02 kg to 9.54 kg. Loads of TN contributed by rainfall could account for <30% of the total discharge.

Table 6.1 TN nutrient balance at Bannister Creek

Month	TN nutrient balance at Bannister Creek study site (kg)		
	TN Input loads - rainwater source	TN Input loads – non-point sources	TN Output loads
Jun, 02	9.54	168.54	178.08
Jul,02	7.24	58.46	65.70
Aug,02	4.35	12.41	16.75
Sep,02	1.92	17.55	19.47
Oct,02	2.88	10.25	13.13
Nov,02	1.31	8.02	9.34
Dec,02	0.23	1.45	1.68
Jan,03	0.02	0.47	0.50
Feb,03	0.46	2.26	2.72
Mar,03	2.85	14.46	17.31
Apr,03	2.95	11.35	14.30
May,03	4.50	17.95	22.45
Total (kg/yr)	38.27	323.17	361.44
Range	0.024-9.54	0.47-168.53	0.49-178.08
Mean ± SE	3.19 ± 0.83	26.93 ± 13.60	30.12 ± 14.32
Median	2.87	11.88	15.53

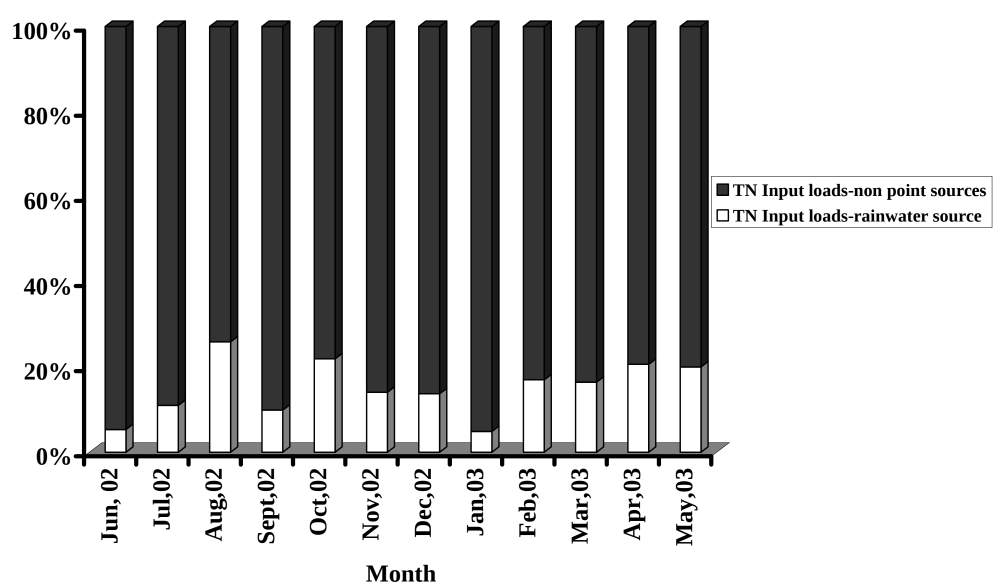


Figure 6.1 TN percent proportions from rainwater and non-point sources at Bannister Creek.

TN nutrient balance from rainfall and non-point sources at Wanneroo is shown in Table 6.2. Between June 2002 and September 2002 and in May 2003 rainfall derived nutrient loads accounted for all of the TN in the discharge within the errors of the discharge estimation. In the rest of the year < 70% of the TN in the discharge is accounted for by rainfall alone.

Table 6.2 TN nutrient balance at Wanneroo

Month	TN nutrient balance at Wanneroo study site [kg (%)]		
	TN Input loads- rainwater source	TN Input loads- non-point sources	TN Output loads
Jun, 02	1.78 (127)	-0.38 (-27)	1.40
Jul,02	1.67 (159.6)	-0.62 (-59.6)	1.05
Aug,02	1.04 (104.5)	-0.04 (-4.5)	0.99
Sep,02	0.73 (133.3)	-0.18 (-33.3)	0.55
Oct,02	0.73 (66.7)	0.37 (33.3)	1.10
Nov,02	0.22 (69.6)	0.1 (30.4)	0.32
Dec,02	0.01 (56.8)	0.01 (43.2)	0.02
Jan,03	0.00	0.00	0.00
Feb,03	0.17 (56.8)	0.13 (43.2)	0.30
Mar,03	0.46 (56.8)	0.35 (43.2)	0.81
Apr,03	0.60 (52.9)	0.53 (47.1)	1.13
May,03	1.23 (108.6)	-0.10 (-8.6)	1.13
Total (kg/yr)	8.64 (98.2)	0.15 (1.8)	8.80
Range	0-1.78	-0.62-0.53	0.02-1.40
Mean ± SE	0.72 ± 0.18	0.013 ± 0.09	0.80 ± 0.13
Median	0.66	0.00	0.99

6.1.2 Total Phosphorus Nutrient Balance

TP nutrient balance and TP proportion from rainwater and non-point sources at Bannister Creek are shown in Table 6.3 and Figure 6.2 respectively. Rainfall directly contributed < 25% of the TP load in the discharge with the exception of the period between April and May 2003 where it reached 49.2 and 43.5% respectively.

Table 6.3 TP nutrient balance at Bannister Creek

Month	TP nutrient balance at Bannister Creek study site (kg)		
	TP Input loads- rainwater source	TP Input loads- non-point sources	TP Output loads
Jun, 02	0.78	12.14	12.92
July, 02.	0.59	4.28	4.86
Aug,02	0.35	1.25	1.60
Sep,02	0.16	3.64	3.79
Oct,02	0.23	0.93	1.16
Nov,02	0.11	0.49	0.59
Dec,02	0.02	0.17	0.19
Jan,03	0.00	0.04	0.05
Feb,03	0.04	0.19	0.22
Mar,03	0.23	1.56	1.80
Apr,03	0.24	0.31	0.55
May,03	0.37	0.57	0.93
Total (kg/yr)	3.11	25.56	28.67
Range	0.002 - 0.78	0.04 - 12.14	0.05 - 12.92
Mean ± SE	0.26 ± 0.07	2.13 ± 0.99	2.39 ± 1.05
Median	0.23	0.75	1.05

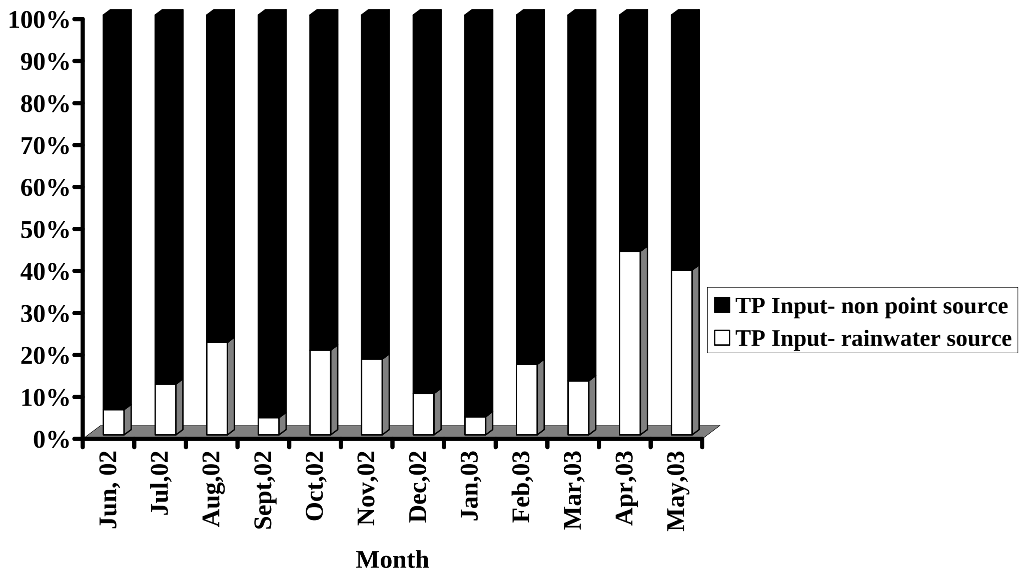


Figure 6.2 TP percent proportions from rainwater and non-point sources at Bannister Creek.

The TP nutrient balance from rainwater and non-point sources at Wanneroo is shown in Table 6.4. In July 2002, TP in the discharge could be accounted for entirely by the load from rainfall. In June 2002, August 2002 and May 2003 it also accounted for a large proportion of the total discharge at 47.7, 77.2 and 91.2% respectively (Figure 6.3). Throughout the rest of year < 30% of TP load in this discharge could be accounted for by rainfall alone, with the exception of September 2002 where it reached 64.5%.

Table 6.4 TP nutrient balance at Wanneroo

Month	TP nutrient balance at Wanneroo study site (kg)		
	TP Input loads- rainwater source	TP Input loads- non-point sources	TP Output loads
Jun, 02	0.14	0.16	0.30
Jul,02	0.14	0.00	0.12
Aug,02	0.08	0.02	0.11
Sep,02	0.06	0.03	0.09
Oct,02	0.06	0.20	0.26
Nov,02	0.02	0.08	0.10
Dec,02	0.00	0.00	0.00
Jan,03	0.00	0.00	0.00
Feb,03	0.01	0.05	0.06
Mar,03	0.04	0.14	0.18
Apr,03	0.05	0.13	0.18
May,03	0.10	0.01	0.11
Total (kg/yr)	0.70	0.81	1.51
Range	0-0.145	-0.214	0-0.304
Mean ± SE	0.06 ± 0	0.07 ± 0	0.13 ± 0
Median	0.05	0.04	0.11

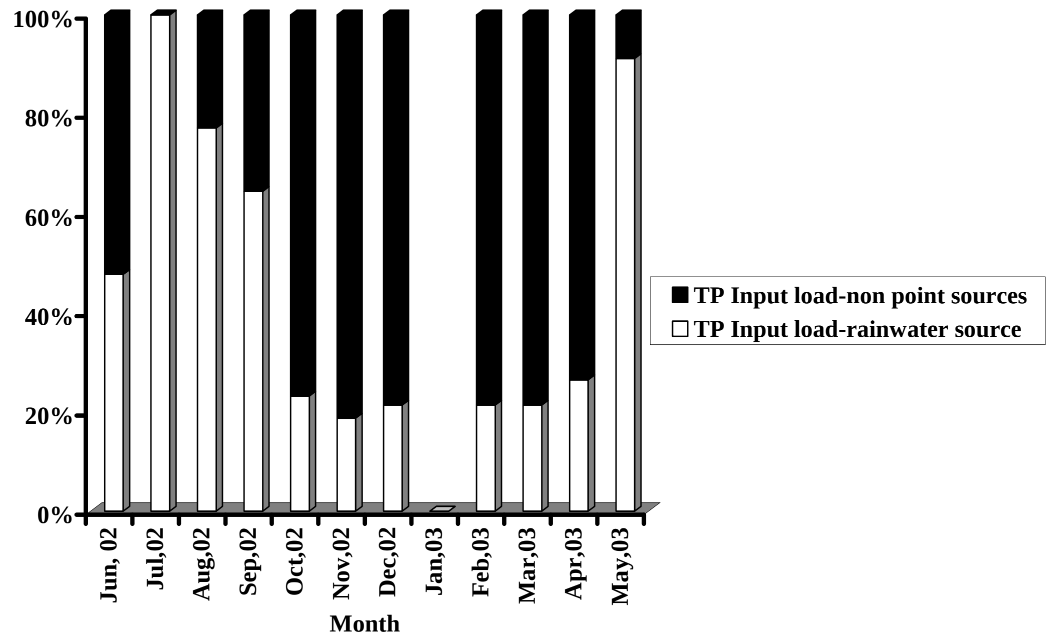


Figure 6.3 TP percent proportions from rainwater and non-point sources at Wanneroo.

6.2 Nutrient Management

6.2.1 Non-point Sources of Nutrients

The major source of TN nutrient input at both sites was from fertiliser application which may be a significant contribution to the non point sources. If a small proportion of the fertiliser input to the catchments was assumed to enter the drainage network by spills directly onto hard surfaces or through surface/subsurface runoff then it could account for a significant proportion of TN load in the discharge (Tables 6.5, 6.6). At Bannister Creek, between October 2002 and February 2003 only 3% of the total fertiliser used could account for most/all of the TN in discharge. However at other times of the year either a greater amount of fertiliser would be required or inputs from other sources. At Wanneroo, 1% of fertilisers entering the drainage easily accounted for all the non-point sources in the catchment.

Table 6.5 The small percentage portion spilled from major nutrient sources caused significant proportion in TN nutrient input load from non-point sources at Bannister Creek

Month	rainwater source kg	non-point sources kg	3% of fertiliser spill kg	TN Output loads kg
Jun, 02	9.54	168.54	9.90	178.08
Jul,02	7.24	58.46	2.64	65.70
Aug,02	4.35	12.41	4.62	16.75
Sep,02	1.92	17.55	10.62	19.47
Oct,02	2.88	10.25	11.48	13.13
Nov,02	1.31	8.02	11.94	9.34
Dec,02	0.23	1.45	2.59	1.68
Jan,03	0.02	0.47	16.40	0.50
Feb,03	0.46	2.26	1.83	2.72
Mar,03	2.85	14.46	2.44	17.31
Apr,03	2.95	11.35	1.94	14.30
May,03	4.50	17.95	4.84	22.45

Table 6.6 The small percentage portion spilled from major nutrient sources caused significant proportion in TN input load from non-point sources at Wanneroo

Month	rainwater source kg	non-point sources kg	1% of fertiliser spill kg	TN Output loads kg
Jun, 02	1.78	0	3.79	1.40
Jul,02	1.67	0	0.72	1.05
Aug,02	1.04	0	0.61	0.99
Sep,02	0.73	0	1.39	0.55
Oct,02	0.73	0.37	0.53	1.10
Nov,02	0.22	0.10	1.02	0.32
Dec,02	0.01	0.01	0.51	0.02
Jan,03	0.00	0	0.43	0
Feb,03	0.17	0.13	0.11	0.30
Mar,03	0.46	0.35	0.13	0.81
Apr,03	0.60	0.53	0.35	1.13
May,03	1.23	-0.10	0.04	1.13

The major source of TP input at both sites was from fertiliser application which may be a significant contribution to the non point sources. If 1% of the fertiliser input to the catchments was assumed to enter the drainage network by spills directly onto hard surface or through surface and subsurface runoff then it could account for a significant proportion of TP load in the discharge (Table 6.7, 6.8). Generally phosphorus leaching into groundwater or subsurface flow is limited. This is because once phosphorus is bound to the soil, it is much less mobile (Brady & Well, 1996; Saarijarvi et al., 2004; Swan River Trust, 1999b). It is not leached into the groundwater and is only exported from the catchment as part of the soil, mainly through artificial drainage systems. However, the leaching pathways into groundwater and subsurface flow can occur when phosphorus fertilisers are applied in sandy soil with low clay and mineral content, such as the sandy soils of the Swan Coastal Plain (Gerritse, 1995; Gerritse, Adeney, Dimmock, & Oliver, 1995). In this case phosphorus may be transported and a high percentage may be leached into groundwater and subsurface flow (Schofield et al., 1985).

At Bannister Creek, 1% of fertiliser entering the discharge in June through to September was not enough to account for all the non-point sources in the catchment but between October 2002 and May 2003 it did account for most/all of the TP from the non-point sources in the catchment with the exception of during March 2003. At Wanneroo, 1% of fertiliser entering the discharge was sufficient to account for all the non-point sources in the catchment.

Table 6.7 The small percentage portion spilled from major nutrient sources caused significant proportion in TP input load from non-point sources at Bannister Creek

Month	rainwater source kg	non-point sources kg	1% of fertiliser spill kg	TP Output loads kg
Jun, 02	0.78	12.14	1.04	12.92
Jul,02	0.59	4.28	0.25	4.86
Aug,02	0.35	1.25	0.48	1.60
Sep,02	0.16	3.64	1.07	3.79
Oct,02	0.23	0.93	1.14	1.16
Nov,02	0.11	0.49	1.18	0.59
Dec,02	0.02	0.17	0.26	0.19
Jan,03	0.00	0.04	1.69	0.05
Feb,03	0.04	0.19	0.18	0.22
Mar,03	0.23	1.56	0.24	1.80
Apr,03	0.24	0.31	0.20	0.55
May,03	0.37	0.57	0.51	0.93

Table 6.8 The small percentage portion spilled from major nutrient sources caused significant proportion in TP input load from non-point sources at Wanneroo.

Month	rainwater source	non-point sources	1% of fertiliser spill	TP Output loads
	kg	kg	kg	kg
Jun, 02	0.14	0.16	1.19	0.30
Jul,02	0.14	-0.02	0.20	0.12
Aug,02	0.08	0.02	0.19	0.11
Sep,02	0.06	0.03	0.45	0.09
Oct,02	0.06	0.20	0.17	0.26
Nov,02	0.02	0.08	0.32	0.10
Dec,02	0.00	0.00	0.16	0.00
Jan,03	0.00	0.00	0.14	0.00
Feb,03	0.01	0.05	0.03	0.06
Mar,03	0.04	0.14	0.04	0.18
Apr,03	0.05	0.13	0.11	0.18
May,03	0.10	0.01	0.01	0.11

6.2.2 Stormwater Load versus Groundwater Base flow Load (Ratio) at Bannister Creek

When considering nutrient and total suspended solid loads of stormwater versus those in groundwater base flow at Bannister Creek (Table 6.9), it can be clearly seen that nutrient and total suspended solid loads of stormwater are up to 28 times greater than those of the groundwater base flow. In winter, the nutrient and total suspended solid loads in stormwater were on average 2 to 5 times greater for nutrients and 2 times for total suspended solids than the loads in groundwater base flow. In spring, they ranged from on average from 1 to 2 times greater for nutrients and only 1 time greater for total suspended solids. In summer, they ranged on average from 1 to 2 times greater for nutrients and 2 times greater for total suspended solids. In autumn, they ranged on average from 7 to 28 times greater for nutrients and 14 times greater for total suspended solids.

The stormwater load versus groundwater base flow load indicates that the nutrient and total suspended loads in stormwater runoff discharged from the drain depended not only on the volume of the stormwater runoff but also on the concentration of the nutrients and total suspended solids accumulated within the catchment. This can be seen from the fact that the nutrient and total suspended solid loads from stormwater were high in winter and autumn compared to loads from groundwater base flow. In autumn particularly, despite low volume of runoff, this ratio was very high. Therefore stormwater runoff in these urban areas is a significant driving force creating increases in nutrient loads in the discharge (Table 6.9).

Table 6.9 Ratio of nutrient and total suspended solid loads from stormwater versus groundwater base flow at Bannister Creek

Nutrient and total suspended solid loads of stormwater vs Nutrient and total suspended solid loads of groundwater base flow						
Parameter	TN	NH4	NOx	TP	FRP	TSS
WINTER						
Range	0 - 26.34	0.64 -54.07	0 - 24.84	0 - 19.82	0 - 20.25	0 - 22.31
Mean ± SE	1.73 ± 0.40	5.33 ± 0.88	1.88 ± 0.36	1.51 ± 0.34	1.79 ± 0.33	1.99 ± 0.43
Median	0.54	2.48	0.86	0.44	0.66	0.53
SPRING						
Range	0 -13.30	0.05 - 26.17	0 - 14.26	0 - 10.45	0 - 9.95	0 - 12.23
Mean ± SE	0.64 ± 0.18	2.25 ± 0.37	0.52 ± 0.18	0.93 ± 0.19	0.51 ± 0.17	0.74 ± 0.23
Median	0.1	1.12	0	0.21	0	0
SUMMER						
Range	0 -51.76	0 - 42.19	0 - 43.05	0 - 53.61	0 - 45.34	0 - 114.85
Mean ± SE	0.72 ± 0.58	0.71 ± 0.47	0.81 ± 0.048	0.77 ± 0.60	0.65 ± 0.50	1.59 ± 1.28
Median	0.02	0.031	0	0.04	0.0004	0
AUTUMN						
Range	0 - 320.13	0 - 450.07	0 - 1411.16	0 - 429.07	0 - 608.99	0 - 996.58
Mean ± SE	8.25 ± 3.83	15.61 ± 6.06	28.02 ± 15.60	7.18 ± 4.72	10.40 ± 6.70	13.50 ± 10.84
Median	0	0.43	1.80	0	0	0

6.2.3 Nutrient Concentration Ratio and Nutrient Discharge per Unit Area

At Bannister Creek, the mean monthly nutrient concentrations (Table 6.10) were mostly within the standard guidelines for nutrients for the protection of aquatic systems based on (Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, 2000) (Table 6.11). This applies to TN, NH_4, TP and FRP. Only the highest exceedance of NOx over ANZECC guidelines is during Apr / May when there is no flow. It varied from 0.21 to 1.27 mg L^{-1}, which is approximately five times higher than the standard guideline. TN and NOx were the dominant nutrient concentrations in stormwater. TN was 17 to 67 times higher than NH_4 and NOx was 5 to 40 times higher. TP and FRP ratio were 2:1 for most of the months, except in September and November 2002 when they were rather high at (4:1 and 3:1 respectively). The standard guideline for total suspended solids (TSS) for the protection of aquatic systems is not available but the ANZECC (2000) guideline for TSS for freshwater production is less than 40 mg L^{-1}. Based on this guideline the mean monthly TSS concentration (6.2 mg L^{-1}) was very low, as it varied between 3.25 and 10.38 mg L^{-1}.

At Wanneroo, some of the average monthly concentrations of nutrients were within the standard guidelines for the protection of aquatic systems based on the Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (2000) (Table 6.12, 6.11). They were TN and NOx. Others (NH_4, TP, FRP) were above the standard guidelines. TN and NOx were the dominant nutrient concentrations in stormwater, 3 to 54 times higher than NH_4 for TN and slightly higher than NH_4 for NOx. TP and FRP ratio were 2:1 for most of the months except in June and August 2002 when they were rather high at 4:1 and 7:1 respectively). Based on the ANZECC (2000) guideline, the mean monthly TSS concentration (14.5 mg L^{-1}) was within the recommended guidelines for freshwater production, as it varied between 0.2 and 64.56 mg L^{-1}.

Table 6.10 Average of monthly nutrient and total suspended solid concentrations and monthly nutrient concentration ratio at Bannister Creek

Average of monthly nutrient concentration at Bannister Creek (mg L^{-1})							Monthly nutrient concentration ratio				
Month	TN	NH_4	NOx	TP	FRP	TSS	TN	NH_4	NOx	TP	FRP
April, 02	1.823	0.046	0.391	0.106	0.084	7.208	39	1	9	2	1
May, 02	1.186	0.062	0.241	0.092	0.042	4.589	20	1	4	2	1
Jun, 02	2.044	0.117	0.619	0.145	0.084	10.382	20	1	5	2	1
Jul, 02	1.814	0.095	0.412	0.136	0.087	7.181	19	1	4	2	1
Aug, 02	1.348	0.080	0.720	0.101	0.061	9.034	17	1	9	2	1
Sep, 02	1.544	0.071	0.369	0.179	0.049	6.155	23	1	5	4	1
Oct, 02	1.362	0.062	0.300	0.107	0.045	6.213	22	1	5	2	1
Nov, 02	1.494	0.069	0.340	0.116	0.046	6.248	22	1	5	3	1
Dec, 02	1.415	0.043	0.212	0.130	0.057	9.435	37	1	5	2	1
Jan, 03	1.530	0.036	0.331	0.124	0.066	6.310	44	1	9	2	1
Feb, 03	1.264	0.019	0.738	0.083	0.048	3.248	67	1	40	2	1
Mar, 03	1.177	0.019	0.644	0.053	0.039	3.468	63	1	33	1	1
Apr, 03	1.302	0.045	1.011	0.066	0.050	3.744	29	1	23	1	1
May, 03	1.411	0.136	1.272	0.063	0.037	3.936	22	1	20	2	1
Mean ± SE	1.48 ± 0.07	0.06 ± 0.01	0.54 ± 0.08	0.11± 0.01	0.06 ± 0	6.2 ± 0.61	32 ± 4.34	1 ± 0	13 ± 3.12	2 ± 0.17	1 ± 0
Median	1.413	0.062	0.401	0.106	0.049	6.231	22	1	7	2	1

Table 6.11 Trigger values of nutrient concentrations for the protection of aquatic systems

Ecosystem type	TN	NH_4	NOx	TP	FRP
AQUATIC ECOSYSTEM	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}
Upland river	0.45	0.06	0.2	0.02	0.01
Lowland river	1.2	0.08	0.15	0.065	0.04
Freshwater lakes	0.35	0.01	0.01	0.01	0.005
Freshwater reservoirs	0.35	0.01	0.01	0.01	0.005
Wetlands	1.5	0.04	0.1	0.06	0.03

Table 6.12 Average of monthly nutrient and total suspended solid concentrations and monthly nutrient concentration ratio at Wanneroo

Average of monthly nutrient and total suspended solid concentration (mg L^{-1})							Nutrient concentration ratio				
Month	TN	NH_4	NOx	TP	FRP	TSS	TN	NH_4	NOx	TP	FRP
May, 02	0.310	0.073	0.099	0.049	0.031	0.200	4	1	1	2	1
Jun, 02	0.388	0.067	0.148	0.084	0.022	1.850	6	1	2	4	1
Jul, 02	0.348	0.020	0.033	0.033	0.015	6.887	54	1	4	2	1
Aug, 02	0.662	0.058	0.048	0.076	0.014	17.141	16	1	1	7	1
Sep, 02	0.481	0.050	0.064	0.062	0.036	5.251	10	1	1	2	1
Oct, 02	0.751	0.140	0.110	0.158	0.107	9.921	6	1	1	2	1
Apr, 02	1.029	0.383	0.770	0.160	0.113	64.556	3	1	2	1	1
May, 02	0.454	0.151	0.052	0.044	0.024	10.200	3	1	0	2	1
Mean ± SE	0.55± 0.09	0.12 ± 0.04	0.17 ± 0.09	0.08 ± 0.02	0.05 ± 0.01	14.5 ± 7.39	13 ± 6.11	1 ± 0	2 ± 0.40	3 ± 0.68	1 ± 0
Median	0.47	0.07	0.08	0.07	0.03	8.40	6	1	1	2	1

Nutrients discharged per unit area at both sites were very small (Table 6.13). TN was discharged from the catchment at a rate of 0.37 g m^{-2} yr^{-1} at Bannister Creek and at 0.05 g m^{-2} yr^{-1} at Wanneroo. TSS was rather high at Bannister Creek.

Table 6.13 Rate of nutrient loads discharged from the catchment per unit area

Time	TN		NH4		NOx		TP		FRP		TSS	
	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN	BC	WN
Load (kg $catchment^{-1}$ yr^{-1})	373.55	9.29	22.57	2.07	160.20	2.65	29.79	1.59	19.67	0.90	3447.34	219.77
Load (g m-^{2} yr^{-1})	0.37	0.05	0.02	0.01	0.16	0.01	0.03	0.01	0.02	0.00	3.45	1.11

6.2.4 Options to Improve Nutrient Management in Stormwater Drainage from Established Residential Area

To improve nutrient management in stormwater drainage from established residential areas, it is essential to target the nutrient load discharged from the drain at the outfall. The nutrient load in stormwater discharged from the drain outfall varies with two factors; one is the volume of stormwater runoff, the second is the nutrient concentration in stormwater runoff. It is essential to minimise either or both of these factors from entering into and discharging from the drain. A wide variety of best management practices (BMPs) will be applicable as principal strategies to reduce the volume of stormwater runoff and nutrients entering the drain at the source and once they enter the drainage system, to reduce the volume of stormwater runoff and therefore nutrients at the end-of-pipe before discharge into receiving waters.

These BMP strategies are in accordance with new approaches in urban stormwater management (Water Sensitive Urban Design) which aim to prevent pollution at the source, maximise infiltration to decrease stormwater runoff, recharge groundwater and minimise change to the natural water balance (Department of Environment, 2004). The removal of vegetation cover from the catchment contributes to increased runoff, as the interception process and the evapotranspiration rates of plants are reduced. Therefore, retaining native vegetation is an important feature of stormwater management (Department of Environment, 2004).

To minimise the nutrient loads discharged from the catchment, all possible sources and pathways should be taken into consideration no matter whether they are major or minor sources and pathways. This is a very important strategy because whatever the sources and pathways involved the water and nutrients they contribute finally end up in the receiving water.

6.2.4.1 At the Source Controls

Many options can be applied to minimise the volume of stormwater runoff and the nutrient concentration in stormwater runoff at the source controls. They are as follows.

- The correct balance of nutrients and fertilisers is taken into consideration to suit plant requirements eg fertilisers applied often and in small amounts during the spring and early autumn period (Department of Environment, 2004, p.101).Over-fertilising will cause leaching. Fertilisers should be stored indoors or in a shed or storage cabinet. Fertiliser application in gardens is one of the major sources of nitrogen and phosphorus input load into the catchments at both sites, based on the questionnaire results. The estimations show that only a small proportion of fertiliser needs to be spilt onto hard surfaces to equal the nutrient loads in the discharge (Table 6.5- 6.8). Therefore the use of BMPs in fertiliser application is an important strategy to reduce nutrient load in both input into and output from the catchment.
- Grass, leaf litter and garden clipping, and other organic matter from garden maintenance (such as tree trimmings, pruning waste) should not enter into the drainage system (Department of Environment, 2004, p.71). They are appropriately disposed by composting, pickup in approved bags or containers etc. If this material enters the stormwater system, it will decompose, consume oxygen and add to the nutrient load input in the stormwater drains. Almost half of the study area at both sites (44% at Bannister Creek and 50% at Wanneroo) comprises lawn and garden areas.
- Native plants in landscaping can be used to reduce water usage in gardens, lawns, and pot plants because they require less water and maintenance (eg. litter, fertiliser and pesticides) (Department of Environment, 2004, p.100). This option will help to reduce water consumption greatly (see details in Figure 4.13). If a reduction of 1% is achieved it will help to reduce the groundwater use in garden watering by approximately 200 or 1000 m^3 $month^{-1}$ at Wanneroo and Bannister Creek respectively between November 2002 and March 2003.

- Large canopy trees are planted over impervious areas at individual properties, to intercept rainfall which helps infiltration of stormwater runoff and reduces stormwater runoff volume discharged from the catchment.
- Reticulation systems are carefully and regularly managed by inspecting, repairing and maintaining (Department of Environment, 2004, p.102). This will help ensure that the correct amount of water is being applied to gardens. Over-watering will cause leaching. In sandy soils, precautions must be taken to ensure that the correct amount of water is utilised. The ‘little and often’ rule should be applied to prevent water percolation below the root zone. From observations made during the study period, reticulation is used by almost every household.
- Streets are cleaned and swept with technologically advanced equipment to pick up finer particulate matter prior to storm events (Department of Environment, 2004, p.59). This will help to reduce a lot of nutrient load discharge from the catchment through the drainage system. This particulate matter is strongly associated with nutrients, heavy metals and other toxic compounds and will be collected and transported by urban stormwater runoff and ultimately accumulate in the receiving waters as sediments (Hart et al.1997). They have been recognised for some time as an important source and sink of pollutants such as nutrients, heavy metals etc. (ANZECC, 1992)
- Impervious areas are minimised by using alternate paving materials (e.g. porous asphalt, pervious concrete, pavers), landscaping, mulch, gravel and cobbles where appropriate to provide ground cover which can help reduce levels of impermeability in the catchment, reducing runoff volume (Department of Environment, 2004, p.122).
- Pet droppings are picked up particularly from impervious surfaces and disposed in plastic bags in garbage bins or toilets, not in stormwater drains.
- Good housekeeping measures are implemented to reduce transfer of pollutants and water to the stormwater system. The questionnaires showed that a total of 76 (46%)

and 21 (33%) of households hosed down their driveways and pathways at Bannister Creek and Wanneroo respectively (Figure 4.9).

- Best management practices (BMPs) are implemented for car washing and maintenance (Department of Environment, 2004, p.112). For instance, wash cars on lawns or pervious areas, use biodegradable and phosphate free detergent, dispose of leftover water into a sink/toilet and not on hard surface areas or in the storm drain. Although the contribution from this source is very low the questionnaire revealed that approximately 30% of households washed their cars on the hard surfaces. Washing vehicles at commercial car washes that recycle water is the ideal.
- Non-structural controls associated with community/public education are implemented with aiming to reduce urban stormwater pollution through a range of educational approaches (such as publications, educational activities and a combination of mass media) to raise public awareness and improve best management practices as well as to encourage the community to understand the link between human activity and the health of ecosystems (Department of Environment, 2004, p.151). This option will help everyone within a catchment area share and be involved in the community to ensure that stormwater management is everyone's responsibility and to protect and conserve stormwater as a valuable resource.

6.2.4.2 In- transit Controls and End-of-pipe Controls

The most effective management of nutrients once in the stormwater system is to settle out the silt and clay particles that have nutrients attached to their surface. A number of studies have shown that most (70-90%) of the suspended particulate matter is transported during high flow events (Cosser, 1989; Cullen, Rosich, & Bek, 1978; Hart, Ottaway, & Noller, 1987) and they are in accordance with the 24 hour sampling which highlights the importance of rainfall and stormwater flow in delivering nutrients in this study and that it is important for transporting many pollutants (e.g. nutrients, heavy metal and other toxic compounds) through aquatic systems. These pollutants are strongly associated with the suspended particulates and colloidal matter (Hart, Breen, & Cullen, 1997).

Therefore BMPs recommended for Bannister Creek site include:

- Gross pollutant traps or sediment traps should be installed to reduce coarse sediment loads entering the stormwater system at the drain outfall because they are used as a vehicle for nutrient transportation in urban runoff (Water and Rivers Commission, 1998c). Gross pollutants are often the first priority of targeted stormwater pollutants in urban catchment for water quality improvement (Walker, Allison, Wong, & Wootton, 1999). Based on a manual for managing urban stormwater quality in Western Australia, gross pollutant traps and sediment traps show a good performance with medium to high sediment trapping efficiency (Water and Rivers Commission, 1998c) or approximately 50% (Allison, Chiew, & McMahon, 1997). For examples, a continuous deflective separation (CDS) system was found to be the best option for trapping efficiency over 50% of a litter load whereas a combination of side entry pit trap (SEPT) system and a CDS system were found their trapping efficiency less than 50% of a litter load (Allison et al., 1998). From this it can be estimated that the TSS load at Bannister Creek can be reduced by up to 1700 kg catchment^{-1} yr^{-1} as well as helping to reduce nutrient loads by 50% as a result (see details of the rate of nutrient loads discharged from the catchment Table 6.13).

- The natural drainage is reclaimed through infiltration systems i.e. grass swales in the lower channel between the end of the pipe and Bannister Creek because there is some open space in this area that could be developed to be an infiltration system. The pollutant trapping efficiency of grass swale is between low and high efficiency for sediments and low for nutrients (Water and Rivers Commission, 1998c) or approximately 69,46, and 56% of the total loads of TSS, TP and TN respectively (Deletic & Fletcher, 2006).

- Filter strips or buffer strips are developed parallel to grass swale from the drain to Bannister Creek. This option has been proposed for the same reason explained above for the grass swale but filter strips have a medium pollutant trapping efficiency for sediment and a low efficiency for nutrients (Water and Rivers

Commission, 1998c) or approximately 61-86% of the sediment (Deletic & Fletcher, 2006).

Therefore BMPs recommended for Wanneroo site include:

- Gross pollutant traps or sediment traps are installed to reduce coarse sediment loads entering the stormwater system at the drain outfall. This option has been proposed for the same reason as proposed in Bannister Creek. It is estimated that TSS load at Wanneroo can be reduced up to 100 kg catchment^{-1} yr^{-1} as well as reducing nutrient load by 50% as a result (see details of the rate of nutrient loads discharged from the catchment Table 6.13).
- Constructed wetland of multi purpose design is established to accommodate wildlife habitat, recreational area, and environmental values because there is a suitably sized open area at Wanneroo where it can be retrofitted and nutrient concentrations and loads at this site are very small. Therefore it is worth developing a constructed wetland not only for stormwater improvement but also for other purposes. Based on a manual for managing urban stormwater quality in Western Australia, the nutrient trapping efficiency of a constructed wetland is between medium and high (Water and Rivers Commission, 1998c) or approximately by 68% the total P load and by 49% the dissolve reactive phosphorus load (Liikanen et al., 2004).

CHAPTER 7: DISCUSSION AND CONCLUSION

This chapter aims at discussion and conclusion on the overall results from chapter 4 to chapter 6 starting with physico-chemical parameters of drainage waters, nutrient concentration of drainage waters, nutrient loads, relationships between nutrient input load and nutrient output load, mass balance of nutrients, and options to improve nutrient management.

7.1 Physico-chemical Parameters of Drainage Waters

7.1.1 pH

All the water samples from both sites were generally neutral to slightly alkaline in pH, as might be expected in sandy soils. Alabaster and Lloyd (1982) suggested that pH of almost all natural water quality guidelines around the world should be retained in the range 6.5 to 9 to protect freshwater aquatic organisms (ANZECC, 1992; CCREM, 1991; USEPA, 1986). All the drainage waters lay within this range.

7.1.2 Conductivity

All the drainage waters studied were fresh at < 1,500 $\mu S\ cm^{-1}$ (Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, 2000) with the exception of routine samples on 11 June 2002; 23 January 2003 and 17 May 2003. The cause is unknown but it is probably caused by many factors influencing the degree to which mineral salts (mainly Na^+, and Cl^-, but also Ca^{2+}, Mg^{2+}, K^+, CO_3^{2-} and SO_4^{2-}) dissociate into ions, such as the amount of electrical charge on each ion, the ion mobility, the temperature of the solution, and storage time as well as catchment geology (APHA, 1998; Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, 2000; Chapman, 1992).

The conductivities of waters at Wanneroo were very low, reflecting the conductivity of rainwater. This illustrates that relatively few ions are collected on the stormwater passage through the catchment. At Bannister Creek, the higher conductivities are most likely a reflection of groundwater input.

The conductivity over 24 hours at Bannister Creek on 24 August 2002 at 18.00 hrs immediately dropped from 800 µS cm^{-1} to 400 µS cm^{-1} and gradually returned back to the same level at nearly midnight. This could probably be explained by field experience encountered in the 24 hour sampling periods that lower conductivity values are often observed following seasonal rainfall. It was observed that on 24 August 2002 a rain event occurred around 15.00 hrs with rain falling between 16.00 hrs to 20.00 hrs. This was probably responsible for the decline seen in conductivity at 18.00 hrs.

7.1.3 Temperature

Water temperature varied seasonally. The graph in Figure 5.27 does not show any sign of groundwater impact on temperature. Generally, groundwater temperatures are close to the mean annual air temperature (Cushing & David, 2001) in particular groundwater in the unconfined aquifer in Perth.

7.1.4 Turbidity

Rainwater and most of the samples at Wanneroo had turbidity lower than recorded at Bannister Creek. However almost all of the water samples varied between 0 and 10 NTU, except during high flows in April and June 2002 where the turbidity reached between 10 to 35 NTU. This was in accordance with a number of studies that have found most of suspended matter (70 to 90%) was transported during high flow events (Cosser, 1989; Cullen et al., 1978; Hart et al., 1987). The influence of rain events can be seen during 24 hours sampled on 24 August 2002 at Bannister Creek, where the turbidity peaked at 93.5 NTU at 18.00 hrs. This could be explained by a small rainfall event that occurred from 16.00 hrs until 20.00 hrs.

7.1.5 Dissolved Oxygen

It was found that the dissolved oxygen concentrations of water samples were high during the wet winter and low in the hot dry summer. This could be explained by the effects of temperature on dissolved oxygen concentrations or by higher flows entraining more oxygen in winter. The oxygen content in waters generally varies with many factors such as temperature, turbulence, salinity, the photosynthesis of algae and plants and rate of transfer from atmospheric pressure (Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, 2000; Chapman, 1992).

7.1.6 Redox Potential (Eh)

The redox potential (Eh) trend of 24 hours hourly samples was higher during the day and lower during the night in every season. This could be explained by the fact that redox potential depends on the gas dissolved in the water potentially due to microbial activity which is directly variable with temperature (Chapman, 1992) and it is easily variable particularly when the water contacts with air (Chapman, 1992).

The redox potential was highly variable at both sites. The degree of variation was slightly higher at Bannister Creek than at Wanneroo. This could be explained by the fact that at Bannister Creek there was groundwater interference with the stormwater. Most of the redox potential values of groundwater samples measured at both sites were negative values or very low positive values.

The redox potential (Eh) describes the oxidation and reduction status of the water (Chapman, 1992). Therefore it is a good indicator for monitoring the change of water quality characteristics of discharge at the initial stage. It implies that our ecological systems have been impacted from some human activities within the catchment and they were needed monitoring and investigating.

7.2 Nutrient Concentration of Drainage Waters

7.2.1 Nitrogen

The TN concentration in the water samples indicated how polluted the water samples were. In this study the TN concentrations of water samples probably resulted from fertiliser application on gardens within the catchment. This is in accordance with the results of the survey questionnaire.

The TN concentration was high in mid April 2002 probably due to a large major storm event that occurred on 16 April 2002. This rainfall event in Perth was measured at 17.6 mm in one hour (equivalent to ARI = 1-2) and 69.6 mm in 24 hours (equivalent to ARI = 2-5). The large runoff flows after the long dry period could collect all particles from the hard surfaces and discharge them into the drain outfall i.e. first flush. The TN concentration is significantly correlated with the volume of the discharge ($P < 0.001$, $r = 0.21$). TN concentration of routine samples at Bannister Creek was also higher than at Wanneroo. This was probably due to the groundwater input in the stormwater at Bannister Creek whereas the stormwater at Wanneroo was only pure rainwater. Evidence from Table 4.8 shows the mean TN concentration in groundwater samples at both sites are more or less the same and very close to 1 mg L^{-1}. When comparing TN concentration at both sites with the ANZECC (2000) guidelines for the protection of aquatic systems in Table 6.11, they were within the standard guidelines.

TN concentration over the 24 hours sampling period varied slightly over the seasons, except on the 24 August 2002 at 18.00 hrs where it peaked because there was rain during the period 16.00 hrs to 20.00 hrs.

TN concentration of groundwater samples was quite consistent at both sites throughout the study period from October 2002 to May 2003 at approximately 1 mg L^{-1} and lay within the standard guideline mentioned above.

A large array of nutrient concentrations has been reported for Australian rivers and streams (Gibbs, Longmore, & Marchant, 1991; Rochford, 1984; Sorokin, 1990). For instance, TN can vary from as low as 0.1-0.2 mg L^{-1} in small, near–pristine mountain streams to > 10 mg L^{-1} in heavily polluted rivers. Comparing TN concentrations of drainage water to the water quality in natural rivers, the concentrations were well within normal bounds.

Ammonium can arise from the breakdown of nitrogenous organic and inorganic matter from different sources such as fertiliser application in soil, pet waste disposal in the lawns and gardens, the reduction of nitrogen gas in water by micro-organisms, the production in the soil-plant system and gas exchange with the atmosphere (see Figure 1.1). The NH_4 concentration of the water from Bannister Creek and Wanneroo was high in winter and gradually dropped to the lowest point in summer, probably due to surface runoff in winter and low concentrations in groundwater which forms the summer flows.

The NH_4 concentrations measured in surface water range from 0.002-1.25 mg L^{-1} nitrogen but can reach 3.37 mg L^{-1} nitrogen in groundwater. Comparing the NH_4 concentrations recorded in this study to the ANZECC (2000) guidelines for the protection of aquatic systems in Table 6.11, found they were mostly within the standard guidelines.

The NOx concentrations of drainage waters varied from a minimum of 0.002 mg L^{-1} for almost all kinds of water samples to a maximum of 2.151 mg L^{-1} for routine samples at Bannister Creek on 17 May 2003. Comparing the NOx concentrations of the water samples to the ANZECC (2000) guidelines for the protection of aquatic systems in Table 6.11 found they were higher than the standard guideline and indicated the nutrient status and level of organic pollution in the catchment.

The TN concentration in stormwater at Bannister Creek and at Wanneroo was compared with TN concentration in five urban main drains (Wharf Street drain, Cockram Street drain, Liege Street drain, Lacey Street drain, Menzies Road drain), Mill Street Main drain, and targeted TN concentrations adopted by the Swan River Trust (Swan River Trust, 1999b), as shown in Table 7.1.

Table 7.1 Comparison of TN concentrations at various sites

Sites	TN mg L^{-1}	Targeted TN (5 yrs) mg L^{-1}	Targeted TN (20 yrs) mg L^{-1}
Bannister Creek	0.38-3.66	2	1
Wanneroo	0.06-1.98	2	1
Five urban main drains	0.24-6.9	2	1
Mills Street main drain	0.27-36	2	1

It can be clearly seen that TN concentrations both at Bannister Creek and Wanneroo are likely to be in the same range as those at the five urban main drains and the Mill Street main drain for the lower level concentrations. For the upper level concentrations, TN concentrations at both Bannister Creek and Wanneroo are lower than those at the five urban main drains and the Mills Street main drain.

If each site is compared with the 20 year TN target for all Swan-Canning catchment sites of 1 mg L^{-1}, it is found that most samples at Bannister Creek are higher than the targeted TN concentration throughout the year but at Wanneroo most samples are lower than the targeted TN concentration except for a small number of samples taken during winter. The TN concentrations measured at Bannister Creek and Wanneroo lay between 0.381 – 3.663 mg L^{-1} with a mean (± se) of 1.46 ± 0.03 mg L^{-1} and 0.125 – 1.957 mg L^{-1} with a mean (±) of 0.523 ± 0.08 mg L^{-1} respectively (see Figure 5.29a). At the five urban main drains it is found that 54% of all samples exceeded the targeted TN of 1 mg L^{-1}. The highest TN concentration at all sites varied from 3.9 mg L^{-1} at Menzies Road drain to 6.9 mg L^{-1} at Lacey Street drain following a rain event (Swan River Trust, 2003a). At the Mills Street main drain it is found that almost all of the samples exceeded the targeted TN of 0.1 mg L^{-1} (Swan River Trust, 2003c).

7.2.2 Phosphorus and Total Suspended Solids

The presence of TP concentration indicates the general nutrient status in the water samples. The major source of phosphorus in this study was fertiliser runoff, based on studying input into the catchment from questionnaires. The TP concentrations during the 24 hours at

Bannister Creek on 24 August 2002 were quite high, around 0.35 mg L^{-1} (three times than usual) at 18.00 hrs. This is probably due to the rain falling around 16.00 hrs to 20.00 hrs causing a runoff increase which collected fertiliser used on lawns and gardens, dust generated over the land from soil erosion and urban contaminants such as pet waste and carwash.

The TP concentration in stormwater at Bannister Creek and Wanneroo was compared with TP concentration in five urban main drains (Wharf Street drain, Cockram Street drain, Liege Street drain, Lacey Street drain, Menzies Road drain), Mills Street Main drain, and targeted TP concentrations adopted by Swan River Trust (Swan River Trust, 1999b) as shown in Table 7.2.

Table 7.2 Comparison of TP concentrations at various sites

Sites	TP mg L^{-1}	Targeted TP (5 yrs) mg L^{-1}	Targeted TP (20 yrs) mg L^{-1}
Bannister Creek	0.04-0.35	0.2	0.1
Wanneroo	0.01-0.24	0.2	0.1
Five urban main drain	0.01-1.2	0.2	0.1
Mill Street main drain	0.08-3.1	0.2	0.1

It is clearly seen that TP concentrations both at Bannister Creek and Wanneroo are more or less within the same range as those at five urban main drains and the Mill Street main drain for the lower level concentrations. For the upper level concentrations, TP concentrations both at Bannister Creek and Wanneroo are much lower than those at the five urban main drains and Mills Street main drain.

If each site is compared with the 20 year TP target for all Swan-Canning catchment sites of 0.1 mg L^{-1}, it is found that half of the samples at Bannister Creek and most of the samples at Wanneroo are lower than the targeted TP concentration throughout the year. The TP concentrations measured at Bannister Creek and Wanneroo lay between 0.041 –0.234 mg L^{-1} with a mean (± se) of 0.107 ± 0.003 mg L^{-1} and 0.011 – 0.239 mg L^{-1} with a mean (±) of 0.068 ± 0.011 mg L^{-1} respectively (see Figure5.30a). At five urban main drains it is found that 64% of all samples exceeded the targeted TP of 0.1 mg L^{-1}. The highest TP concentration at all sites varied from 0.17 mg L^{-1} at Cockram Street drain to 1.2 mg L^{-1} at Liege Street drain following a rain event (Swan River Trust, 2003a). At the Mills Street main drain it is found that almost all of the samples exceeded the targeted TP of 0.1 mg L^{-1} (Swan River Trust, 2003c). Based on the targeted TP of 0.2 mg L^{-1}, it was found that 77% of the samples have a TP concentration at or above o.2 mg L^{-1} (Swan River Trust, 2003c).

The FRP concentrations of water samples varied in a similar manner to TP concentrations. FRP concentration in stormwater at Bannister Creek and Wanneroo was compared with FRP concentration in Liege Street drain, Mills Street Main drain and the FRP standard based on the Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, 2000), as shown in Table 7.3.

Table 7.3 Comparison of FRP concentrations at various sites

Sites	FRP mg L^{-1}	FRP (Standard) mg L^{-1}
Bannister Creek	0.02-0.19	0.005-0.03
Wanneroo	0.01-0.17	0.005-0.03
Liege Street drain	0.006- 0.67	0.005-0.03
Mill Street main drain	0.008-2.8	0.005-0.03

Based on limited New Zealand data, Quinn (1991) recommended that the FRP concentration should be below the ranges of 0.015-0.03 mg L^{-1} to maintain any control of periphyton growth. Chessman and Hitton (1989) also suggested that the same ranges can possibly be applied to Australian conditions as well. It is clearly seen that FRP concentrations of all the samples at all sites were over the FRP standard.

TSS concentration in stormwater at Bannister Creek and Wanneroo was compared with TSS concentration in five urban main drains, Mills Street Main drain and the TSS standard of 25 mg L^{-1} determined by the Agriculture Western Australia (Agriculture Western Australia, 1996) and 40 mg L^{-1} determined by Liston and Maher (1997), as shown in Table 7.4.

Table 7.4 Comparison of TSS concentrations at various sites

Sites	TSS mg L^{-1}	TSS (Standard) mg L^{-1}
Bannister Creek	0.2-61	25, 40
Wanneroo	0.02-65	25, 40
Five urban main drains	1-58	25, 40
Mill Street main drain	>1-180	25, 40

It is clearly seen that TSS concentrations both at Bannister Creek and Wanneroo are likely to be in the same range as those at the five urban main drains but lower than those found at Mills Street main drain.

If each site is compared with the standard recommended by Agriculture Western Australia and Liston and Maher as mentioned above, it is found that most samples at Bannister Creek and Wanneroo are lower than the recommended standard. Only a few samples exceeded both standards. The majority of TSS concentrations measured at Bannister Creek and Wanneroo lay between 2 and 10 mg L^{-1} (see Figure 5.30c). At the five urban main drains it was found that only a few samples exceeded the recommended standard of 40 mg L^{-1} (Liston & Maher, 1997). The highest TSS concentration at all sites ranged from 48 mg L^{-1} at Cockram Street drain to 58 mg L^{-1} at Lacey Street drain following a rain event (Swan River Trust, 2003a). At the Mills Street main drain it was found that almost all of the samples contained less than the recommended TSS standard of 25 mg L^{-1} (Agriculture Western Australia, 1996).

The nutrient concentrations of most stormwater samples at all sites mentioned above increased following the rainfall event (Swan River Trust, 2003a, 2003c).

7.3 Nutrient Load

Nutrients are typically delivered from the catchment either as point or diffuse sources, depending on the scale of influence. Fertilisers and detergents from residential land use are well known as the nutrient sources on the Swan Coastal Plain (Gerritse & Adeney, 1992; Swan River Trust, 1999a). Residential urban areas can also produce nutrient loss through widespread fertilisation of gardens and parks (Gerritse & Adeney, 1992). The transport of diffuse sources of nutrients to waterways can occur via a variety of hydrologic pathways, such as surface run-off, sub-surface flow and groundwater. However, both nitrogen and phosphorus are mobilised and transported through the catchment by very different mechanisms (David & Bela, 2000; Swan River Trust, 2003b) such as plant uptake, volatilisation, denitrification, leaching, mineralisation, nitrification and surface entrainment.

7.3.1 Nutrient Input Loads

The nutrient input in the residential urban catchment came from various sources, mainly from natural phenomena and human activities. The natural source was from atmospheric deposition, both wet (with rainfall) and dry (direct fallout) deposition. Human activities were the main contribution of nutrient input into a catchment and were mostly associated with our routine lives, based on the results from the survey questionnaires. The research study revealed that the major sources of nutrient input into a catchment at both study sites were fertiliser applications and vehicle emissions whereas the minor sources of nutrient input were groundwater usage, pet waste, and rainwater. The smallest source was car washing.

The major sources of TN input loads at both study sites were fertiliser application and vehicles emission, approximately 2707 and 1512 kg yr^{-1} or 2.71 and 1.51 g $m^{-2}yr^{-1}$ at Bannister Creek (see Table 4.7) and 962 and 3024 kg yr^{-1} or 4.87 and 15.32 g m^{-2} yr^{-1} at Wanneroo (see Table 4.8). The minor sources were from groundwater, rainwater, and pet waste varying around 170 to 820 kg yr^{-1} or 0.2 to 0.8 g $m^{-2}yr^{-1}$ at Bannister Creek and around 40 to 90 kg yr^{-1} or 0.2 to 0.4 g $m^{-2}yr^{-1}$ Wanneroo. Considering all sources, the total TN input entering into each catchment was about 5438 kg yr^{-1} or 5 g $m^{-2}yr^{-1}$ at Bannister Creek and about 4155 kg yr^{-1} or 21 g $m^{-2}yr^{-1}$ at Wanneroo. Difference in N inputs to the catchment between Wanneroo and Bannister Creek was due primarily to vehicle emissions. In most other parameters Bannister Creek was equal or higher than Wannero. This shows the important of vehicle emissions as an input and the importance of knowing the accuracy of the calculations for vehicle emissions is very important. This research has been made an attempt to quantify the roughly amounts from the secondary sources. To achieve a precise figure, an experimental design should be conducted to specific purpose.

Nitrogen losses by leaching and denitrification generally become a problem only when nitrogen fertilisation exceeds the amount needed to fill the gap between crop uptake needs and the supply from these other sources (Brady & Well, 1996; Henderson-Sellers & Markland, 1987). This will be addressed later in this chapter.

The major sources of TP input loads at both study sites were fertiliser application of approximately 824 kg yr^{-1} or 0.82 g $m^{-2}yr^{-1}$ at Bannister Creek and 302 kg yr^{-1} or 1.53 g $m^{-2}yr^{-1}$ at Wanneroo. The minor sources were from groundwater, rainwater and pet waste varying around 7.5 to 31.9 kg yr^{-1}r or 0.008 to 0.03 g $m^{-2}yr^{-1}$ at Bannister Creek and around 0.80 to 2.89 kg yr^{-1} or 0.004 to 0.015 g $m^{-2}yr^{-1}$ at Wanneroo.

Considering all sources, the total TP input entering into each catchment was about 877 kg yr^{-1} or 0.88 g $m^{-2}yr^{-1}$ at Bannister Creek and about 308 kg yr^{-1} or 1.56 g $m^{-2}yr^{-1}$ at Wanneroo

The nutrient input survey of this study was compared with other studies (Water and Rivers Commission and Gerritse) in Table 7.5. It is clearly shown that each site was variable in itself, however they were within a certain range both in TN and TP input loads. Exceptions were for N input load at Wanneroo and P input load from Gerritse, which were a bit higher than other studies.

Table 7.5 Nutrient input survey results

Sources of nutrient input survey	Nitrogen Input g m-2 yr-1	Phosphorus Input g m-2 yr-1
Bannister Creek (Author)	5	0.88
Wanneroo (Author)	21	1.56
Aerial Photography Interpretation (WRC, 2002)	9.3	1.75
Survey Questionnaires (WRC, 2002)	10.2	2.7
Gerritse (1992)	11	4.6

Nutrient input load into each residential catchment was variable. This could be explained by the fact that nutrient input load into residential catchment areas is influenced by many factors such as climate, soil types and land form, garden type and community attitude to fertiliser application variable with time, and population density (Water and Rivers commission, 2002b; Wong & Morrison, 1994). For the reliability of the data, it is hard to determine because some respondents will overestimate and some will underestimate. When they are averaged, they are very close to the real situations.

7.3.2 Nutrient Output Load

Nutrient output loads at both study sites were calculated in daily load, monthly load, yearly load, and g m^2 yr^{-1} from data shown in Table 5.10 and are summarised in Table 7.6. All of the daily and monthly nutrient and TSS output loads were high during winter with a peak in June 2002 and gradually decreased to the lowest level in November 2002 and then remained consistent until March 2003 before increasing again (Figure 5.42, 5.43). The nutrient and TSS output loads discharged from the drain outfall followed a similar pattern to the stormwater discharge from the drain (see Figure 5.1 and 5.2). This indicated that the volume of discharge from the catchment was significantly influential on the nutrient and TSS loads.

The yearly output loads of all nutrients and TSS discharged from Bannister Creek were much higher than at Wanneroo. Although this is a reflection of the difference in the size of the catchment area between sites it is also seen in comparison between sites.

In terms of g m^{-2} yr^{-1}, the quantity of TN discharged from a catchment was equal to 0.37 g m^{-2} yr^{-1}at Bannister Creek and 0.05 g m^{-2} yr^{-1} at Wanneroo. This result was in contrast to the nutrient input load study conducted by a questionnaire survey. From the surveyed questionnaires, it was found that the quantity of nutrient input entering into each catchment were equal to 5.88 g m^{-2} yr^{-1}at Bannister Creek and 33.07 g m^{-2} yr^{-1} at Wanneroo.

Table 7.6 Nutrient output load at Bannister Creek (BC) and Wanneroo (WN)

Nutrient Output Load	Site	Daily Load (g)	Monthly Load (kg)	Yearly Load (kg)	Load (g m-2 yr-1)
TN	BC	0-63,464	0.50-178.08	373.55	0.37
	WN	2-786	0.02-1.40	9.29	0.05
NH4	BC	0-1795	0.01-7.46	22.57	0.02
	WN	0-293	0.01-0.43	2.07	0.01
NOx	BC	0-21,367	0.10-56.24	160.20	0.16
	WN	0-588	0.01-0.81	2.65	0.01
TP	BC	0-4,754	0.05-12.92	29.79	0.03
	WN	0-190	0.00-0.30	1.59	0.01
FRP	BC	0-4,272	0.03-10.31	19.67	0.02
	WN	0-148	0.00-0.18	0.90	0.005
TSS	BC	0-969,102	1.26-2113.55	3447.34	3.45
	WN	2-49, 314	0.32-74.66	219.77	1.11

In Table 7.7, the TN loads in stormwater at Bannister Creek and Wanneroo are compared with TN loads found in River Road, Cockram, Council Depot, Bywater, Adenia, Champlin, and Wharf catchments in a study conducted by Wong and Morrison (Wong & Morrison, 1994) .

It is clearly seen that TN and TP loads both at Bannister Creek and Wanneroo are variable in the same range as those at River Road, Cockram, Council Depot, Bywater, Adenia, Champlin, and Wharf.

Table 7.7 Comparison of TN and TP output loads at various catchments

Catchments	TN g m^{-2} yr^{-1}	TP g m^{-2} yr^{-1}
Bannister Creek	0.37	0.03
Wanneroo	0.05	0.01
River Road	0.84, 0.20	0.07, 0.05
Cockram	0.59, 0.26	0.16, 0.07
Council Depot	0.48, 0.18	0.04, 0.02
Bywater	0.66, 0.18	0.05, 0.01
Adenia	0.35, 0.11	0.04, 0.01
Champlin	0.31, 0.18	0.02, 0.01
Wharf	-,0.19	-0, 0.03

N.B. The first figures shown in TN and TP column at River Road, Cockramp downwards to Wharf were the results of the year 1992. The second figures were the results of the year 1993.

7.4 Relationships between Nutrient Input Load and Nutrient Output Load

The relationships between nutrient input load and nutrient output load were analysed by using the correlation analysis (Table 7.8). From the result, it revealed that there was no relationship between nutrient input load and nutrient output load for TN and TP at both sites on a monthly basis. This result indicates that the output load estimated from the depth of drainage water at the outfall and its nutrient concentration using the Manning Equation and the input load estimated from the surveyed questionnaire, are not correlated. This is probably due to many factors involved such as experimental design and question survey errors.

Table 7.8 Correlations between nutrient input load and nutrient output load

Parameter	Bannister Creek (n = 12)	Wanneroo (n = 12)
TN	r = 0.04 (NS)	r = 0.35 (NS)
TP	r = 0.14 (NS)	r = 0.53 (NS)

7.5 Mass Balance of Nutrients

A mass balance of a nutrient or nutrient budget in an ecosystem is an attempt to account for the quantity of nutrient input loads ('income') to an ecosystem, and the quantity of nutrient output loads ('losses') from an ecosystem (Calow, 1999). Accumulation of total mass in a system is equal to the difference between input and output load (see more details in Appendix 5 Nutrient Balance / Mass Balance of Nutrients).

7.5.1 Total Nitrogen (TN)

The TN mass balance at Bannister Creek and Wanneroo is summarised in Table 7.9.

From Table 7.9, it was found that the percent storage within the catchment was quite high with an average of 92.61% at Bannister Creek and 99.78% at Wanneroo. The percent storage varied from the minimum of 65.73% in June 2002 at Bannister Creek and 99.58% in May 2003 at Wanneroo to a maximum of 99.94% in January 2003 at Bannister Creek and 100% in December 2002 and January 2003 at Wanneroo.

Although the mechanisms that might contribute to N retention in the catchment were not measured, they were modelled using the rate of nitrogen processes provided by Dr Christian Zammit (Department of Environment) for Bannister Creek. The rates for N processes were mineralisation (0.00001964 g m^{-2} d^{-1}), volatilisation (0.0004 g m^{-2} d^{-1}), nitrification (0.00284 g m^{-2} d^{-1}), denitrification (0.0124 g m^{-2} d^{-1}), plant uptake (0.1546 g m^{-2} d^{-1}), fixation (0.00294 g m^{-2} d^{-1}), surface entrainment (0.00101 g m^{-2} d^{-1}), and vertical entrainment or leaching (0.00153 g m^{-2} d^{-1}).

Table 7.9 TN mass balance at Bannister Creek (BC) and Wanneroo (WN).

Month	Total TN Input Load kg		Total TN Output Load kg		Discharge %		Storage %	
	BC	WN	BC	WN	BC	WN	BC	WN
Jun, 02	519.59	645.17	178.08	1.40	34.27	0.22	65.73	99.78
Jul,02	265.97	337.64	65.70	1.05	24.70	0.31	75.30	99.69
Aug,02	324.14	324.84	16.75	0.99	5.17	0.31	94.83	99.69
Sept,02	519.69	401.58	19.47	0.55	3.75	0.14	96.25	99.86
Oct,02	574.46	317.37	13.13	1.10	2.29	0.35	97.71	99.65
Nov,02	673.40	367.85	9.34	0.32	1.39	0.09	98.61	99.91
Dec,02	357.01	318.79	1.68	0.02	0.47	0.01	99.53	99.99
Jan,03	835.52	309.52	0.50	0.00	0.06	0.00	99.94	100.00
Feb,03	348.76	279.44	2.72	0.30	0.78	0.11	99.22	99.89
Mar,03	367.96	283.26	17.31	0.81	4.70	0.29	95.30	99.71
Apr,03	285.45	299.81	14.30	1.13	5.01	0.38	94.99	99.62
May,03	365.74	269.94	22.45	1.13	6.14	0.42	93.86	99.58
Total (kg/yr)	5437.69	4155.21	361.44	8.80	6.65	0.21	93.35	99.79
Min	265.97	269.94	0.50	0.00	0.06	0.00	65.73	99.58
Max	835.52	645.17	178.08	1.40	34.27	0.42	99.94	100.00
Average	453.14	346.27	30.12	0.73	7.39	0.22	92.61	99.78
Std Dev	174.02	101.25	49.62	0.48	10.71	0.14	10.71	0.14

In addition, nutrient plant uptake rates supplied by Professor William Stock (School of Natural Science, Edith Cowan University) were used. Biomass of lawn was 300-400 g m^{-2} (as dry weight) with a range of nitrogen of 1 to 4% or approximately 2% of N (this is just to minimise the over and under load estimation) and with a variation of phosphorus from 0.1 to 0.4% or approximately 0.2% P with the same reason as above (Professor William Stock *pers comm*). Biomass of shrubs is 3.5 kg m^{-2} (as dry weight) with a nitrogen composition of 1.5% and a phosphorus composition of 0.15% (Stock & Allsopp, 1992).

Using the information above, the nitrogen load for each process in each pathway was quantified as shown in Table 7.10. The quantification of nutrient loads from each nutrient process was derived by multiplying the nutrient rates (acquired from Dr. Christian Zammit and Prof William Stock) and the area of lawn and garden (acquired from aerial photograph interpretation).

7.5.1.1 Plant Uptake

Grass clippings; seeds, flowers, and leaf litters; pruning wastes and tree trimmings from lawns and gardens should be well managed through collecting, chipping if necessary, composting or disposing appropriately otherwise they can be a major source of nitrogen in urban runoff (Cowen & Lee, 1973; Kluesener & Lee, 1974). They contain high total nitrogen content in leaves, typically about 1-2% of dry weight (Cowen & Lee, 1973; Hicks, Wesely, Lindberg, & Bromberge, 1986; Prasad et al., 1980; Stock & Allsopp, 1992) and may be carried away by surface runoff. It is suggested that all plant materials should be collected and made into compost to use in the lawns and garden as nutrient recycling to keep the nutrient budget balanced as well as minimise the use of chemical fertilisers.

Table 7.10 Processes, load and percentage of nitrogen at Bannister Creek (BC) and Wanneroo (WN).

Mass Balance	Quantity of Nitrogen (kg yr-1)		Percentage (%)	
	BC	WN	BC	WN
Total TN Input Load	5,912	4,263		
Human Activities (Quest)	5,438	4,155		
Fixation	474	108		
Total TN Input Load	28,249 (13,107)	6,345 (2,903)		
Probability Load	28,249 (13,107)	6,345 (2,903)		
Total TN Storage	624	142	2.21 (4.76)	2.24 (4.89)
Mineralisation	3	1	0.01 (0.02)	0.01 (0.02)
Nitrification	458	104	1.62 (3.50)	1.64 (3.59)
Surface Entrainment	163	37	0.58 (1.24)	0.58 (1.28)
Total TN Output Load	27,625 (12,483)	6,203 (2,761)	97.79 (95.24)	97.76 (95.11)
TN output load from the drain	374	9	1.32 (2.85)	0.14 (0.30)
Plant uptake	24,939 (9,797)	5,669 (2,227)	88.28 (74.75)	89.34 (76.71)
Volatilisation	65	15	0.23 (0.49)	0.23 (0.51)
Denitrification	2,000	455	7.08 (15.26)	7.17 (15.66)
Leaching	247	56	0.87 (1.88)	0.88 (1.93)

The figures shown in brackets were estimated by using the information from Professor William Stock and the rest was from Dr Christian Zammit. This is to show how variable the two sources of information were.

Residents who live in any water catchment should bear this in mind and follow best management practices (BMPs) to minimise nutrient pollution and reduce nutrient export from the catchment. In these two study areas the lawn and garden areas occupied approximately around 44% at Bannister Creek and 51% at Wanneroo of the total catchment area. Definitely all these kinds of activities (eg fertiliser application, groundwater usage, pet waste disposal, vehicle emission and carwash) are not avoidable but highly influenced to imminent nutrient pollution within the catchments.

7.5.1.2 Denitrification

Denitrification is the return of fixed N to the atmosphere and completion of the N cycle. Denitrification is not really important other than as a loss of N from the catchment. It seems likely to be not important but it is an inter-connected via hydrological, sedimentary and atmospheric cycles and finally end up in the receiving waters.

7.5.1.3 Vertical Entrainment or Leaching

Nitrate readily leaches through soil and can be transported with subsurface flow to the receiving waters or groundwater (Chapman, 1998; Lovett & Price, 1999). Leaching of nitrates can be a major cause of serious environmental problems. For instance nutrient losses, contamination in drinking water, and eutrophication and associated problems (i.e. the degradation of aquatic ecosystems caused by the depletion of dissolved oxygen by decomposed algae, flavour and toxicity produced by a certain species of algae making the water unfit for drinking etc).

Nitrogen lost through leaching in the form of nitrate is generally carried by drainage waters to the groundwater. The high solubility of nitrates generally results in leachates having high nitrate concentrations (Brady & Well, 1996; Henderson-Sellers & Markland, 1987). Nitrate leaching probably could be a serious problem at both of our study sites as high concentration found in surface waters. At Wanneroo there has been increasingly urbanisation around the Joondalup lake. This urbanisation will probably influence human activities such as the use of fertiliser in lawns and gardens, and municipal and industrial wastewaters can be a significant source of nitrates (Gerritse, Wallbrink, & Murray, 1998; Wong & Morrison, 1994). Bannister Creek is groundwater fed and the watertable is very low (Balla, 1994). Therefore this site is more vulnerable to nitrate leaching. Both sites are compounded with sandy soil usually low in clay, humus and minerals (Gozzard, 1983; Jordan, 1986; Seddon, 1972) which favour nitrate leaching (Schofield et al., 1985). There is increasing concern in the scientific community over the effects of nitrogen pollution resulting from fertiliser inputs to food and fibre production systems (Galloway & Cowling, 2002).

To minimise leaching process, fertilisers should be used carefully and sparingly through minimising and limiting fertiliser applications. Consideration should be given to stopping application of fertiliser if rain is forecasted. Reticulation systems should be inspected periodically to ensure that the right amount of water is being applied and that excessive runoff is not occurring. Leaks in reticulation systems should be repaired as soon as they are observed. Care must be taken with sandy soils at both of the study sites to ensure that the correct amount of water is applied. The ‘little and often’ rule should apply to minimise excess watering and ensure water percolation below the root zone does not occur.

The study result from fertiliser application in Figures 4.7 and 4.8 revealed that both the percentage of households and the amount of fertiliser applied to lawns / garden beds / pot plants were high during rainy period from June to November. Therefore it is really important to follow the advice mentioned, not only the fertiliser application but also all related activities as a complete cycle to prevent leaching nitrogen pollution.

7.5.1.4 Volatilisation

Volatilisation is one of nutrient processes which contribute to partly of Total TN output load. Ammonia produced in the soil-plant system is released to the atmosphere as a gas. Volatilised ammonia will ultimately contribute to wet and dry deposition. Although this may not be in the source catchment, the quantity of ammonia released through this process was estimated to be around 0.2-0.5%. Ammonia (NH_3) in high concentrations at a certain pH level is harmful to aquatic life and consequently damaging to the ecological balance of water bodies.

7.5.1.5 Nitrification

Nitrification is the process through which ammonium nitrogen from both organic and inorganic nitrogenous compounds is oxidised to nitrite nitrogen and nitrate nitrogen by certain autotrophic soil bacteria. The quantity of nitrate produced through this process was figured to be around 2-4%. Nitrate can pose several serious environmental problems as mentioned above. This is very important for catchment processes because the nitrate ion (NO_3^-) is a common form of nitrogen found in natural waters (Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, 2000). It may be biochemically reduced to nitrite (NO_2) by denitrification processes. Usually under anaerobic conditions, the nitrite ion is rapidly oxidised to nitrate (Brady & Well, 1996; Wetzel, 2001). NOx readily leaches through soils and is primarily associated with subsurface and groundwater flows (Chapman, 1998; Lovett & Price, 1999).

7.5.1.6 Horizontal Entrainment or Surface Entrainment

Surface entrainment, or surface runoff focused on vegetated areas, is the process through which water moves across the soil surface and may entrain nutrients from the soil surface by dissolving or eroding and suspending them. The particulates that are too large to be suspended in the water may be transported by rolling over the soil surface. The quantity of nutrient loss through stormwater by surface entrainment was estimated to be around 0.6-1.3 % for N at both sites.

Nitrogen, mainly as dissolved inorganic nitrogen (NOx; and NH_4), is readily soluble in water and is rapidly transported through the catchment via surface run-off. Ammonia losses are also associated with surface run-off and erosion because it is associated with pet waste and recently applied fertilisers (Chapman, 1998; Heathwaite, Johnes, & Peters, 1996).

Mobilisation of soluble nitrogen species depends on many factors such as rates of mineralisation / assimilation process with organic matter and the rate of microbial denitrification which releases nitrogen gas (Heathwaite et al., 1996; Reddy & D'Angelo, 1994). Studies have shown that microbial denitrification of NOx can be an important removal process for nitrogen in saturated soils (Slater & Capone, 1987; Smith & Duff, 1988). It is estimated that only 20 % of nitrogen added to a sandy catchment may ultimately reach the body of water (Valiela et al., 1997). The estimates from this study were based on information provided by Dr Christian Zammit and Professor William Stock and were variable around 10 and 21% respectively. These figures were derived from the summation of all possible processes (e.g. leaching process, denitrification process, nitrification process and volatilisation process) involved in Table 7.10. These figures are all within the same range.

7.5.1.7 Surface Runoff from Stormwater Drain

Nitrogen transported by surface run-off on impervious surfaces in Perth metropolitan areas is likely to be extremely fast and may enter the waterway within hours or days after a storm event begins (Gerritse, 1993). This was the case with total nitrogen output load discharged from the two drains which accounted for only 0.14-2.85% of the total TN input.

Although the TN output load from the drains was relatively small (compared to those sites studied by Wong and Morrison as shown in Table 7.7) when discharged into Bannister Creek (374 kg yr^{-1} or 0.37 g m^{-2} yr^{-1}) and Lake Joondalup (9 kg yr^{-1} or 0.05 g m^{-2} yr^{-1}), it cannot be overlooked as potentially it could cause adverse impacts.

7.5.2 Total Phosphorus (TP)

The nutrient mass balances of total phosphorus (TP) at Bannister Creek and Wanneroo were summarised in Table 7.11.

Table 7.11 TP mass balance at Bannister Creek (BC) and Wanneroo (WN)

Month	Total TP Input Load kg		Total TP Output Load kg		Discharge %		Storage %	
	BC	WN	BC	WN	BC	WN	BC	WN
Jun, 02	108.46	119.97	12.92	0.30	11.91	0.25	88.09	99.75
Jul,02	28.42	21.16	4.86	0.12	17.12	0.56	82.88	99.44
Aug,02	49.97	19.31	1.60	0.11	3.21	0.57	96.79	99.43
Sept,02	109.22	45.93	3.79	0.09	3.47	0.20	96.53	99.80
Oct,02	117.00	17.05	1.16	0.26	0.99	1.50	99.01	98.50
Nov,02	124.52	32.53	0.59	0.10	0.48	0.30	99.52	99.70
Dec,02	31.37	16.45	0.19	0.00	0.61	0.03	99.39	99.97
Jan,03	174.66	14.02	0.05	0.00	0.03	0.00	99.97	100.00
Feb,03	23.92	3.64	0.22	0.06	0.94	1.77	99.06	98.23
Mar,03	29.73	4.86	1.80	0.18	6.04	3.61	93.96	96.39
Apr,03	24.35	11.23	0.55	0.18	2.26	1.63	97.74	98.37
May,03	55.37	1.95	0.93	0.11	1.68	5.63	98.32	94.37
Total (kg/yr)	877.01	308.10	28.67	1.51	3.27	0.49	96.73	99.51
Min	23.92	1.95	0.05	0.00	0.03	0.00	82.88	94.37
Max	174.66	119.97	12.92	0.30	17.12	5.63	99.97	100.00
Average	73.08	25.68	2.39	0.13	4.06	1.34	95.94	98.66
Std Dev	51.08	32.19	3.63	0.09	5.28	1.71	5.28	1.71

From Table 7.11 it was found that the percent storage within the catchment was quite high with an average of 95.94% at Bannister Creek and 98.66% at Wanneroo, whereas the percent discharge from the catchment was very low with an average of 4.06% at Bannister Creek and 1.34% at Wanneroo. The percent storage varied from the minimum of 83% in July 2002 at Bannister Creek and 94% in May 2003 at Wanneroo to a maximum of 100% in October 2002 to January 2003 at Bannister Creek and 100% in December 2002 and January 2003 at Wanneroo. To identify the quantity of phosphorus load in the phosphorus processes and their pathways is quite complicated but to a lesser extent compared to nitrogen processes (National Research Council, 2000). However, this study tried to simplify the calculation method to account quantitatively for phosphorus load in each phosphorus process and their pathways by using the rate of phosphorus processes and their pathways from the literature review mentioned below.

In this study the rate of phosphorus processes was collected from Dr Christian Zammit, (Department of Environment) for Bannister Creek. The rates for P processes were plant uptake (0.0651 g m^{-2} d^{-1}), surface entrainment (0.000182 g m^{-2} d^{-1}), and vertical entrainment or leaching (0.00837 g m^{-2} d^{-1}).

Information on the phosphorus processes at Wanneroo is not available but in this study all those phosphorus process rates at Bannister Creek were applied in Wanneroo, even though the conditions at Wanneroo are not exactly the same as at Bannister Creek to provide an indication of the possible phosphorus losses.

These figure rates and their mechanisms of phosphorus processes are very important because they illustrate the amounts and destinations of these phosphorus compounds within the catchment. It could probably be used as a basis to better understand nutrient pollution in our environment. This will help catchment managers plan and manage their catchments to achieve the aims targeted in Integrated Catchment Management (ICM).

Using the information above, the phosphorus load for each process in each pathway was quantified as shown in Table 7.12. The quantification of nutrient loads from each nutrient process was derived by multiplying the nutrient rates (acquired from Dr. Christian Zammit and Prof William Stock) and area of lawn and garden (acquired from aerial photograph interpretation).

The figures shown in brackets were estimated by using the information from Professor William Stock and the rest was from Dr Christian Zammit. This is just to show how variable the information was.

From Table 7.12 it was found that most phosphorus input load was used by plant uptake accounting for 40-88% at both sites. The rest was utilised by leaching (around 11-57%) and surface runoff via hard surface (only 0.3-1.2%).

Table 7.12 Processes, load and percentage of phosphorus at Bannister Creek (BC) and Wanneroo (WN).

Mass Balance	Quantity of Phosphorus (kg yr^{-1})		Percentage (%)	
	BC	WN	BC	WN
Total TP Input Load	877	308		
Human Activities (Quest)	877	308		
Total TP Input Load	11,909 (2,388)	2,702 (538)		
Prob Load	11,909 (2,388)	2,702 (538)		
Total TP Storage	29	7	0.25 (1.23)	0.25 (1.24)
Surface Entrainment	29	7	0.25 (1.23)	0.25 (1.24)
Total TP Output Load	1,180 (2,359)	2,696 (531)	99.76 (98.79)	99.75 (98.76)
TP output load from the drain	29	2	0.24 (1.20)	0.06(0.28)
Plant uptake	10,501 (980)	2,387 (223)	88.18 (41.04)	88.34 (41.41)
Leaching	1,350	307	11.34 (56.54)	11.36 (57.07)

7.5.2.1 Plant Uptake

Plant uptake was considered as consuming the highest proportion of nutrients compared to other processes. It indicates that grass clippings; seeds, flowers, and leaf litter; pruning wastes and tree trimmings from the lawns and gardens should be well managed otherwise they may be a major source of phosphorus in urban runoff (Cowen & Lee, 1973; Kluesener & Lee, 1974). They contain high total phosphorus content in leaves, typically about 0.15-0.2% of dry weight (Cowen & Lee, 1973; Hicks et al., 1986; Prasad et al., 1980; Stock & Allsopp, 1992), and may be carried away by surface runoff. It is suggested that all plant materials should be collected and made into compost to use in gardens as nutrient recycling to keep the nutrient budget balanced as well as minimising the use of chemical fertilisers (only as a supplement).

Residents who live in any catchment should bear this in mind and follow best management practices (BMPs) to minimise nutrient pollution and reduce nutrient export from the catchment. In these two study areas the lawn and garden areas occupied approximately around 44% at Bannister Creek and 51% at Wanneroo of the total catchment area.

7.5.2.2 Vertical Entrainment or Leaching

Leaching of phosphorus indicates that phosphorus may be transported or leached into groundwater and subsurface flow. This is generally very limited because phosphorus is chemically combined with iron, magnesium, calcium, and aluminium by being adsorbed onto the surfaces of clay and silt particles and organic matter in most soils (Brady & Well, 1996; Swan River Trust, 1999b). Sandy soils in the Swan Coastal Plain, in particular the Bassendean Sands at Bannister Creek and the Spearwood Sands at Wanneroo, contain little iron and aluminium oxides and little chemical attraction due to low phosphorus adsorption indices (Gerritse, 1995; Gerritse et al., 1995). Therefore phosphorus from input load can leach through these soils rapidly. Travel and residence time of phosphorus in the catchment will depend on the recharge rate to groundwater, rate of adsorption to soil particles and the extent of soil saturation (Gerritse & Adeney, 1992; Gerritse, Barber, & Adency, 1990). Gerritise (1993) described the sandy soils on the Swan Coastal Plain as having low nutrient retention capacity and as readily leaching phosphorus, with a travel time of phosphorus transported via sub-surface flows or groundwater in the order of one to fifty years per metre.

7.5.2.3 Horizontal Entrainment or Surface Entrainment.

The quantity of phosphorus loss by surface entrainment was estimated to be around 0.3-1.3% at both sites. Surface entrainment is a process particular to phosphorus because it occurs in a sedimentary cycle rather than as a gaseous cycle like the nitrogen cycle (Brady & Well, 1996). This process depends on both chemical and physical factors. Chemical factors influencing this process are soil pH, which determines phosphorus species available in the soil solution (Henderson-Sellers & Markland, 1987), and the adsorption of soil capacity to attract or associate with nutrient ion or compound (Henderson-Sellers & Markland, 1987). The physical factors of most concern are to do with vegetative cover, such as the structure of plants above the ground as a barrier to surface runoff and the capacity of the root structure to bind the soil particles together to resist erosion (Henderson-Sellers & Markland, 1987).

7.5.2.4 Surface Runoff from Stormwater Drain

In contrast to phosphorus transported via sub-surface flows or groundwater, phosphorus transported by surface run-off on impervious surfaces in the Perth metropolitan areas is likely to be extremely fast and may enter the waterway within hours or days after a storm event begins (Gerritse, 1993). This was the case for total phosphorus output load discharge from the drain which accounted for only 0.3-1.2% of the mass balance.

Although the TP output load from the drains was relatively small (compared to those sites studied by Wong and Morrison as shown in Table 7.7) when discharged into the Bannister Creek (29 kg yr^{-1} or 0.03 g m^{-2} yr^{-1}) and Lake Joondalup (2 kg yr^{-1} or 0.01 g m^{-2} yr^{-1}), it cannot be overlooked as it could potentially cause adverse impacts.

7.5.3 Final Fate of Nutrient

Based on the study results shown in Table 7.10 and 7.12 for TN and TP mass balance, it is revealed that plant uptake is the most important nutrient processes in generating the nutrient load for TN and TP accounted for 75% and 40% respectively. Leaching is the second important nutrient processes in creating the nutrient load for TP accounted for 55%. The rest of the nutrient processes are a minor cause of generating the nutrient loads and they reveal 15% for denitrification, 3.50% for nitrification, more or less than 2% for TN leaching and TN and TP surface entrainment, and less than 1% for volatilization and mineralization.

As mentioned above in the nutrient mass balance and as shown in Figure 1.1, it is clearly seen that no matter what pathway nutrients follow from arrival in the catchment, they eventually find their ways to the receiving waters of a lake, river, and the sea or the ocean.

Nutrient runoff in stormwater has caused the Swan and Canning rivers to show the signs of a system under stress in the early 1990s. Algal blooms and fish deaths in the Swan River and the toxic blue-green blooms in the Canning River were increased to an unacceptable level. Therefore the Swan-Canning Cleanup Program was launched by the State Government in May 1994 to restore and protect the rivers – the scenic heart of Perth – for this and future generations. The stormwater drain at Bannister Creek discharges nutrients into Bannister Creek and Bannister Creek is a tributary of the Canning River, therefore the stormwater drain at Bannister Creek has partly contributed to this algal bloom phenomenon in the Swan and Canning rivers.

7.6 Options to improve nutrient management

Nitrogen and phosphorus load discharged from the stormwater drain was only one of the many contributors' causing nutrient pollution problems. The mass balance nutrient study implies that options to improve management of N and P should be focused on the minimisation of nitrogen and phosphorus losses in all pathways, no matter whether they are small or large in quantity.

This is because wherever pathways they go they are all inter-connected via hydrological, sedimentary and atmospheric cycles and finally end up in the receiving waters such as lakes, reservoirs, rivers and the oceans. In a holistic view once they are all together they might synergistically and cumulatively contribute to an enormous nutrient pollution in the catchment.

To achieve improvements with regard to nutrient pollution, either in these two residential study catchments or in others elsewhere in the world, the concepts, principles and strategies proposed in options to improve nutrient management are likely to be effective and practical because they are very straightforward and scientifically reasonable criteria, as well as adherent to new approaches in urban stormwater management which aim to prevent, reduce, and eliminate nutrients at all stages within the site. All options described in this thesis to improve nutrient management were developed from the water urban sensitive design (WSUD) manual prepared by the Department of Environment (Department of Environment, 2004) and should be applied to prevent nutrients entering the catchment at the sources in the initial stage as the first priority with all options proposed in the source control. Once the nutrients enter the catchment, all options proposed in in-transit controls and end-of -pipe controls are applied to reduce and eliminate nutrients.

7.7 Limitations and Future Research

Limitations to the thesis are the followings.

The scope of the study is quite broad compared to the experimental design to collect the data in the field both in quantitative and qualitative data over the aims target to achieve.

Collection of stormwater discharge has a certain level of accuracy due to no autosampler available during the study period. This will cause error in calculation of discharge in routine water sample and particularly to storm event sample which need precisely predicting on the time storm event to occur.

Data needed to achieve the quantification of input loads are from the questionnaires, secondary data from the government and private sector, the expert's advice and knowledge. This information has certain level of reliability.

For future research conducting to achieve the likely aims of this project. This project should be divided into many sub projects and working in the laboratory scale with the thoroughly well in experimental design to achieve various aspect outcome of catchment nutrient processes and pathway as well as human activities occurring within the catchments. Each sub-project should be carefully, closely and thoroughly observe and monitor to what is going on in the catchment.

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APPENDIX 1 - QUESTIONNAIRES

APPENDIX 1.1

AN EXAMPLE OF THE QUESTIONNAIRE

This questionnaire is going to collected at the end of "October".

Residential survey questionnaire to identify Nitrogen & Phosphorus sources from the households' application

Collection Month: ______October, 2002____________________

1. Street Address

____

2. Water usage

2.1 This month did you hose down the driveway or path.

☐ No ☐ If yes how often/how many time? _____

2.2 This month have you watered the lawn/garden bed/ pot plant.

☐ No please go to question 2.3

If Yes, please complete the table below as accurately as possible.

Place	Hose		**Reticulation**	
	how often this month	**how long each time**	**how often this month**	**how long each time**
Lawns				
Garden beds				
Pot plants				

2.3 What type of water do you use for these areas?

Type of Water	**Driveways**	**Lawns**	**Garden beds**	**Pot plants**
Tap water				
Bore water				

3. Fertilizer application

3.1 This month have you applied any type of fertiliser to the lawns/garden beds/ pot plants.

☐ No please go to question

If Yes, please complete the table below

Place	Chemicals		Organic materials (compost & manures)	
	how many grams (Totally)	**What brand**	**how many kilos (Totally)**	**What brand/type**
Lawns				
Garden beds				
Pot plants				

4. Car wash

4.1 This month did you wash your car at home.

☐ No please go to question 5

If Yes, please fill in the table below

Place	**how often this month**	**With what brand of detergent**
Lawns		
Hard surface (concrete/road)		

5. Pet waste disposal

5.1 Do you have any pets at home?

☐ No

If Yes, please fill in the table below

Pet	Number	Where did you dispose of their waste ?
Dogs		
Cats		
Birds		
Others, please specify		

Thank you for your time

Please place the completed form in the bag provided, in a secure location near your mailbox at the end of the month (if it is not collected within a week, please phone Pao on [redacted]

APPENDIX 1.2

A FORM OF DISCLOSURE FOR RESEARCH

Statement of Disclosure

Dear Participants,

Firstly, may I introduced myself. I am an international student studying Environmental Management, School of Natural Sciences, Faculty of Computing, Health and Sciences at Edith Cowan University. This questionnaire is a part of my study to fulfill the requirements for the award of Doctor of Philosophy (Environmental Management).

As you may know, accumulation of nutrients in soils and their subsequent leaching into waterways contribute significantly to the environmental degradation of developed areas and need to be managed on a catchment scale. Community awareness of the link between the consumption of nutrients and the deterioration of water quality is essential to the effective implementation of any strategies to minimise the impact of nutrients on water quality.

My research aims to reduce contamination of environments receiving stormwater drainage from small established residential catchments by evaluating the likely effectiveness of adopting best management practices for minimising nutrient contamination of stormwater compared to using conventional treatment methods at stormwater discharge points. Specifically, the research will quantify major sources of nitrogen and phosphorus entering urban residential catchments and nitrogen and phosphorus stormwater discharge from urban residential catchments on two of Perth's major dunal systems as well as assess and compare key pathways for nitrogen and phosphorus to enter the drainage network from catchment sources on two of Perth's major dunal systems. Finally, recommendation will be produce to reduce nutrient discharge in stormwater, particularly comparing Water Sensitive Urban Design initiatives with conventional discharge solutions.

This questionnaire aims to find out the pollution sources, to cope with such problems and to make their impact as small as possible. You are one of a small group of residents who have been randomly selected to participate in this survey. Because I have deliberately chosen only a relative small sample. It is very important to me that I have as many surveys returned as possible. I would be very grateful if you would complete and put it in a secure location near your mailbox. Then I can collect it at the end of every month. By doing so, you will help to improve our environment for a better quality of life.

This survey should take you about 5-10 minutes to complete. Most of the questions are simple and straight forward in compliance with your routine life. However, if you have further comments to make on these questions, please feel free to write on the paper next to the questions. I welcome all additional comments. Your survey answers will remain confidential. All data will be presented in aggregated (combined) form. It will not be possible to identify individual resident's responses.

If you have any questions about this survey, please do not hesitate to contact:

Pao Khwanboonbumpen, Phone [redacted], e-mail: s.pao@ecu.edu.au

If you have any concerns about the project or would like to talk to an independent person, you may contact Julie Robert (Bannister creek catchment group coordinator) [redacted]

Yours Sincerely,

(Surasites Khwanboonbumpen)

Ph.D student, School of Natural Sciences

Faculty of Communicaitons, Health and Sciences

Edith Cowan University

Perth, Western Australia 6027

APPENDIX 1.3

A FORM OF INFORMED CONSENT FOR RESEARCH

Sources of Nitrogen and Phosphorus in stormwater drainage from established residential areas and options for improved management

Consent Form

I have been informed about all aspects of the above research project and any questions I have asked have been answered to my satisfaction.

I agree to participate in this activity, realising I may withdraw at any time.

I agree that the research data gathered for this study may be published provided I am not identifiable.

Participant’s Name :________________________________ Date:____________________

Signature :____

APPENDIX 2 - ABBREVIATION

Australian Height Datum (AHD):

The datum used to determine elevations in Australia. This uses a national network of benchmarks and tide gauages and sets mean sea level as zero elevation.

Average Recurrence Interval (ARI)

Average Recurrence Interval (ARI) is defined as the average, or expected, value of the periods between exceedance of a given rainfall total accumulated over a given duration.

Central Business District (CBD)

Dissolved Organic Phosphorus (DOP)

Dissolved organic phosphorus is organically combined phosphorus. The dissolved forms of phosphorus are measured after filtering the sample through a pre-washed 0.45 µm pore diameter membrane filter.

Filterable Reactive Phosphorus (FRP)

Basically this is soluble phosphate (orthophosphate), readily available to plants and algae. (see also orthophosphate).

Integrated Catchment Management (ICM)

River management based on the understanding that a river system cannot be divided into stretches – there is a continuum of interaction throughout the system – and cannot be isolated from surrounding land. The quantity of water in a river is influenced by the surrounds (by run-off) and influences the surrounds (by flooding). Moreover, there is a continuum between riverwaters and lateral groundwaters. Thus management of water quality has to be carried out in an integrated way, with all these factors in mind. Integrated Catchment models try to capture this complexity and are used, for example, to simulate the input of run-off and its effects on water quality.

Nitrogen (N)

A gaseous element (Atomic Number = 7, relative Atomic Mass = 14.0067). In the free elemental states nitrogen exists as an unreactive, diatomic gas, dinitrogen (N_2; melting point = -209.9 $^{\circ}$C; boiling point = -195.8 $^{\circ}$C), which is the most abundant component of the atmosphere (78.1% by volume). Global recycling of the element is described by a nitrogen cycle in which the major fluxes are within terrestrial and marine biospheres and dead organic matter. Nitrogen is essential for plant growth and is fixed from the atmosphere principally by bacteria in the soil in nitrogen fixation process. The element takes oxidation states from -3 to +5 and combines to form a variety of important trace gases and ions, for example: dinitrogen oxide (or nitrous oxide; N_2O); nitrogen monoxide (or nitric oxide; NO); nitrogen dioxide (NO_2); ammonia (NH_3); nitrite (NO_2^-); nitrate, NO_3^-); and ammonium (NH_4^+);

The oxides of nitrogen (NOx) in the sample (essentially nitrate, NO_3 and some nitrite (NO_2^-) readily available to plants and algae, but requires more energy to use as a nitrogen source than ammonium.

Ammonium (NH_4)in a sample, readily available to plants and algae, in most cases preferred nitrogen source to nitrate

Orthophosphate or Filterable Reactive Phosphorus (FRP)

Orthophosphate is also called dissolved inorganic phosphorus (DIP) or filterable reactive phosphorus(FRP). It’s an available form to plants and algae

AQMS

AQMS stands for Air Quality Monitoring Station. It is a kind of network around Perth for monitoring air quality (various gases and particulates), also wind, temperature etc. A google search on "AQMS Perth" comes up with the Perth Photochemical Smog Study report which defines the term.

Phosphorus Retention Index (PRI)

Phosphorus Retention Index is an index which purposely provides field staffs, watershed planners, and land users with a tool to assess the various landforms and management practices for potential risk of phosphorus movement to water bodies. The ranking of Phosphorus Index identifies sites where the risk of phosphorus movement may be relatively higher than that of other sites.

Suspended solids (SS)

Non – living organic particles occurring in the water column of flowing waters, lakes or the marine environment, and maintained in suspension by physical forces. Unless filtered out by filter – feeding organism, or decomposed by attached microbes, such particles ultimately sink to form sediments. Suspended solids are defined experimentally as the dry mass of solid obtained by filtering a known volume of water through a filter with specified pore size, and are measured in milligrams per litre.

Total Dissolved Solids (TDS)

The term "residue" applies to the substances remaining after evaporation of a water sample and its subsequent drying in an oven at a given temperature. It is approximately equivalent to the total content of dissolved and suspended matter in the water since half of the bicarbonate (the dominant anion in most waters) is transformed into CO_2 during this process.

Total Nitrogen (TN)

Total Nitrogen is all of the nitrogen (organic nitrogen and inorganic nitrogen) in the sample. Organic nitrogen consists mainly of protein substances (e.g. amino acids, nucleic acids and urine) and the product of their biochemical transformations (e.g. humic acids and fulvic acids). As it is formed in water principally by phytoplankton and bacteria, and cycled within the food chain, it is naturally subject to the seasonal fluctuations of the biological community. Organic nitrogen is usually determined using the Kjeldahl method which gives total ammonia nitrogen plus total organic nitrogen (Kjeldahl N). The difference between the total nitrogen and the inorganic forms gives the total organic nitrogen content.

Total Phosphorus (TP)

Total Phosphorus is all of the phosphorus (organically combined phosphorus and all phosphates) in the sample. Phosphorus concentrations are usually determined as orthophosphates, total inorganic phosphates. The dissolved forms of phosphorus are measured after filtering the sample through a pre-washed 0.45 µm pore diameter membrane filter. Particulate concentrations can be deduced by the difference between total and dissolved concentrations.

Total Suspended Solids (TSS)

The term "solids" is widely used for the majority of compounds which are present in natural waters and remain in a solid state after evaporation (some organic compounds will remain in a liquid state after the water has evaporated). TSS applies to the dry weight of the material that is removed from a measured volume of water sample by filtration through a standard filter.

Water Sensitive Urban Design (WSUD)

Water Sensitive Urban Design (WSUD) is the integration of water cycle management which covers a large aspect of drinking water, stormwater runoff, waterway health, and sewage treatment into urban planning and design.

APPENDIX 3 - INPUT LOAD ESTIMATION

APPENDIX 3.1 ESTIMATION OF PHOSPHORUS INPUT LOAD FROM CARWASH

3.1.1 Amount of Phosphorus Used Per Wash

The amount of cleaning detergent (include carwash detergent and dishwashing detergent) used in this study was based on the amount labelled on the detergent container. The amount varied from 10 mL up to 60 mL per time. The amounts frequently used were around 10 mL. 20 mL and 30 mL in general brand names. Consequently this study assumes that amount of detergent used per time was equal to 20 mL or g/ time and standard of Phosphorus is not exceeding 25 mg L^{-1} according to the Australian Ecolabel Program: Australian Voluntary Environmental Labelling Standard "Hand Dishwashing Detergents" (Draft Standard No: 17-2004). Therefore, each time of car washing on the hard surface area, the amount of Phosphorus entered into the residential catchment approximately 0.5 mg.

3.1.2 Estimation of Phosphorus Input Load from Carwash on January, 02

At Wanneroo

Number of houses = 203 houses

Ave frequency of carwash on hard surface area = 0.14 time month $^{-1}$ house^{-1}

Amount of TP produced per carwash = 0.5 mg

% contribution of cleaning detergent = 32 percent

TP input from carwash = (203×0.14×0.5×32)/100

= 4.55 TP mg month $^{-1}$

= 0.0046 TP g month $^{-1}$

= 0.0000046 TP kg month $^{-1}$

At Bannister Creek

Number of houses = 799 houses

Ave frequency of carwash on hard surface area = 0.18 time month $^{-1}$ house^{-1}

Amount of TP produced per carwash = 0.5 mg

% contribution of cleaning detergent = 54 percent

TP input from carwash = $(799 \times 0.18 \times 0.5 \times 54)/100$

= 39 TP mg month $^{-1}$

= 0.039 TP g month $^{-1}$

= 0.000039 TP kg month $^{-1}$

APPENDIX 3.2 ESTIMATION OF NUTRIENT INPUT LOAD FROM FERTILISER

3.2.1 Amount of Fertiliser Application

Amount of fertiliser used in each study area acquired from the questionnaires collected on a monthly basis from the residents at the study sites. It derived from summation of all types of fertiliser applied in lawn, garden and pot plant in each household at each study site.

The fertiliser in this study included potting mix and mulch because they were nutrients or based fertilisers added or contained active mineral and especially graded compost pine bark or enriched with plant food (eg. nitrosol) for good nutrition.

3.2.2 N: P Ratio of Fertiliser

N: P ratio of fertiliser used in this study has developed from N: P ratio which is available on the website of fertiliser companies namely Baileys, Scotts, Richgro and Yates by averaging those on line N: P ratio values. The N: P ratio used in this study equals to 13.45652174: 3.597246377or 13.5: 3.6 and 3.43 : 1.13 : for chemical and organic fertiliser respectively.

3.2.3 Examples of Estimation of Nutrient Input Load

Nutrient input load from fertiliser application can be estimated by multiplying the percentage of Nutrient available in the fertiliser and the amount of fertiliser used in a certain period.

At Wanneroo

Nutrient input load from fertiliser on a monthly basis is equal to amount of fertiliser used in each month multiply with the percentage of nutrient available in fertiliser.

Below was an example of estimation of nutrient input load from fertiliser on October, 02.

Number of total houses	=	203 houses
Total samples on Oct, 02	=	64 cases
Amount of fertiliser used in Oct, 02	=	381.95 kg total samples^{-1}
	=	(35.95 chem fer + 346 org fer)
	=	5.97 kg house^{-1}
	=	(0.56 chem fer + 5.41 org fer)
	=	1212 kg catchment^{-1}
	=	(114.02 chem fer + 1097.47 org fer)
% Nitrogen in the fertiliser	=	13.46 percent for chem fertiliser
	=	3.43 percent for org fertiliser
% Phosphorus in the fertiliser	=	3.60 percent for chem fertiliser
	=	1.13 percent for org fertiliser
TN input from fertiliser	=	$(114.02\times13.46) + (1097.47\times3.43)/100$
	=	53.02 (15.34 + 37.68) kg catchment $^{-1}$

Vice versa

TP input from fertiliser	=	$(114.02\times3.60) + (1097.47\times1.13)/100$
	=	16.54 (4.10 + 12.44) kg catchment $^{-1}$

At Bannister Creek

Nutrient input load from fertiliser on a monthly basis is equal to amount of fertiliser used in each month multiply with the percentage of nutrient available in fertiliser.

Number of total houses = 799 houses

Total samples on Oct, 02 = 171 cases

Amount of fertiliser used in Oct, 02 = 1469 kg total samples^{-1}

= (314 chem fer + 1155 org fer)

= 8.60 kg house $^{-1}$

= (1.84 chem fer + 6.75 org fer)

= 6865 kg catchment^{-1}

= (1467.05 chem fer + 5398.16 org fer)

% Nitrogen in the fertiliser = 13.46 percent for chem fertiliser

= 3.43 percent for org fertiliser

% Phosphorus in the fertiliser = 3.60 percent for chem fertiliser

= 1.13 percent for org fertiliser

TN input from fertiliser = $(1467.05\times13.46) + (5398\times3.43)/100$

= 382.61 (197.46 + 185.15) kg catchment $^{-1}$

Vice versa

TP input from fertiliser = $(1467.05\times3.60) + (5398\times1.13)/100$

= 113.81 (52.81 + 61) kg catchment $^{-1}$

APPENDIX 3.3 ESTIMATION OF NUTRIENT INPUT LOAD FROM GROUNDWATER

Nutrient input load from groundwater usage can be estimated by multiplying the concentration of nutrients in groundwater and the volume of groundwater used in the catchment.

3.3.1 Groundwater Concentration

Groundwater concentration can be acquired from conducting chemical analysis of nutrients in the laboratory by the methods described in APHA (1998).

3.3.2 Groundwater Volume

Groundwater volume in this study can be divided into two categories. One is the amount of groundwater used in driveway / pathway and lawn, garden, and pot plant by hose. The other is the amount of groundwater used in driveway / pathway and lawn, garden, and pot plant by reticulation.

Amount of groundwater used by hose at each study site can be quantified by multiplying the flow rate of hose, duration of hose down each time, frequency of hose down in a certain period, total number of houses in the study area and % contribution of groundwater. In this study the flow rate of hose can be determined by measuring the volume of water running from the hose in a certain time (In this case the optimal rate is justified and equivalent to 10 L min^{-1}). Duration of hosing each time and frequency of hosing in a certain period can be calculated from questionnaires by summation of an average of the duration and frequency hosing at driveway / pathway and lawn, garden and pot plant per house. Also the number of house can be acquired from the questionnaires. Based on this criterion, Volume of ground water (hose) is written in an equation on a monthly basis as shown below.

Volume of GW (hose) = flow rate (litres/minute) × duration of hosing each time (mins/time) × frequency of hosing per month (time/month/house) × number of houses in the study area (houses) × % contribution of gw

Amount of groundwater used by reticulation at each study site can be estimated by measuring the reticulation rate. Then multiply this reticulation rate with, duration of switch on each time, frequency of switch on in a certain period, total number of houses in the study area and % contribution of groundwater. The reticulation rate is measured by placing 15 plastic containers in random across the lawn and garden areas and switch on the reticulation system to water in a certain period. After finish watering, measure the depth of each plastic container and average their values to keep as a record for groundwater consumption (for example 1cm / 10 mins). Based on this criterion, Volume of groundwater (reticulation) is written in an equation on a monthly basis as shown below.

Volume of GW (reticulation) = reticulation rate (cm or metre/minute) × area of lawn and garden (square metre) × period of reticulation each time (mins/time) × frequency of reticulation per month (times/month/house) × number of houses in the study area (houses) × % contribution of gw.

3.3.3 Examples of Estimation of Groundwater Volume on October, 02

At Wanneroo

At driveway (on October,02)

Flow rate = 0.01 $m^3 \ min^{-1}$

Hose down period = 7.5 mins $time^{-1} \ house^{-1}$

Frequency of hose down = 0.10 time $house^{-1}$

Number of houses = 203 houses

% contribution of gw = 9 percent

Volume of gw (hose driveway) = $(0.01\times7.5\times0.10\times203\times9)/100$

= $0.14\ m^3$

At Lawn Garden and Pot plant (on October,02)

Flow rate = $0.01\ m^3\ min^{-1}$

Hose down period (how long) = 10.94 mins $time^{-1}\ house^{-1}$

Frequency of hose down (how often) = 7.51 time $house^{-1}$

Number of houses = 203 houses

% contribution of gw = 28 percent

Volume of gw (hose LGP) = $(0.01\times11\times7.5\times203\times28)/100$

= $46.72\ m^3$

At Lawn Garden and Pot plant (on October,02)

Reticulation rate = $0.001073997\ m\ min^{-1}$

Area of lawn garden & pot plant = $100461.9241\ m^2$ study $site^{-1}$

= $495\ m^2\ house^{-1}$

Period of reticulation (how long) = 13.515625 mins $time^{-1}\ house^{-1}$

Frequency of reticulation (how often) = 5.65625 time $house^{-1}$

Number of houses = 203 houses

% contribution of gw = 28 percent

Volume of gw (reticulation) $= (0.001 \times 495 \times 13.5 \times 5.65 \times 203 \times 28)/100$

$= 2309.55 \ m^3$

Total volume of groundwater (hose+retic) = 0.14 + 47 + 2146 m3 month^{-1}

$= 2356.417292 \ m^3$

At Bannister Creek

At driveway (on October, 02)

Flow rate = 0.01 $m^3 \ min^{-1}$

Hose down period = 7.5 mins time^{-1} house^{-1}

Frequency of hose down = 0.25 time house^{-1}

Number of houses = 799 houses

% contribution of gw = 18 percent

Volume of gw (hose driveway) $= (0.01 \times 7.5 \times 0.25 \times 799 \times 18) / 100$

$= 2.68 \ m^3$

At Lawn Garden and Pot plant (on October,02)

Flow rate = 0.01 $m^3 \ min^{-1}$

Hose down period (how long) = 8.402941176 mins time^{-1} house^{-1}

Frequency of hose down (how often) = 6.647058824 time house^{-1}

Number of houses = 799 houses

% contribution of gw (hose LGP) = 61 percent

Volume of gw (hose LGP) = $(0.01 \times 8.40 \times 6.65 \times 799 \times 61)/100$

= 273 m^3

At Lawn Garden and Pot plant (on October,02)

Reticulation rate = 0.001073997 m min^{-1}

Area of lawn garden & pot plant = 441952.1388 m^2 study $site^{-1}$

= 553 m^2 $house^{-1}$

Period of reticulation (how long) = 17.37647059 mins $time^{-1}$ $house^{-1}$

Frequency of reticulation (how often) = 7.805882353 time $house^{-1}$

Number of houses = 799 houses

% contribution of gw = 61 percent

Volume of groundwater (reticulation) = $(0.001 \times 553 \times 17.37 \times 7.81$

$\times 799 \times 61)/100$

= 39386.41 m^3

Total volume of groundwater (hose+retic) = 2.68 + 273 + 36564 m^3

= 39659.43 m^3

3.3.4 Nutrient Input from Groundwater

Nutrient input load from groundwater usage can be estimated by multiplying the concentration of nutrients in groundwater and the volume of groundwater used in the catchment.

Example of Estimation of Nutrient Input Load from Groundwater (on October, 02)

At Wanneroo

Nutrient input load from gw = Nutrient Input load from Driveway and LGP

TN concentration = 891 mg m^{-3}

TP concentration = 13 mg m^{-3}

Volume gw (hose driveway) = 0.14 m^3

Volume of gw (hose LGP) = 47 m^3

Volume of gw (reticulation LGP) = 2309 m^3

Total input of gw (hose retic LGP) = 2356 m^3

Total volume of gw (hose&retic) = 2356 m^3

TN input from groundwater = (891×2356) mg

= 2099196 mg

= 2.09 kg

= 2.10 kg

TP input from groundwater = (13.37×2356) mg

= 31499.72 mg

$= 31.49$ g

$= 0.0315$ kg

At Bannister Creek

Nutrient input load from gw = Nutrient Input load from Driveway and LGP

TN concentration = 845 mg m^{-3}

TP concentration = 35 mg m^{-3}

Volume gw (hose driveway) = 2.68 m^3

Volume of gw (hose LGP) = 273 m^3

Volume of gw (reticulation) = 39386 m^3

Total input of gw (hose retic LGP) = 39659 m^3

Total volume of gw (hose&retic) = 39659 m^3

TN input from groundwater = (845×39659) mg

$= 33868786$ mg

$= 33868.786$ g

$= 33.87$ kg

TP input from groundwater = (35×39659) mg

$= 1388065$ mg

$= 1388.065$ g

$= 1.38$ kg

APPENDIX 3.4 ESTIMATION OF NUTRIENT INPUT LOAD FROM PET WASTE

3.4.1 Fertiliser Value of Cat and Dog Manure

The composition of cat and dog manure is similar. The faeces contain about 0.7% nitrogen (N), 0.25%phosphate and 0.02% potash (K_2O). the urine contains about 1.1% N, 0.01% P_2O_5 and O.5% K_2O. (R.E. Hall and Emmett Schulte, 2004)

3.4.2 Estimated Nitrogen Output From Dogs

Estimation of the amount of nitrogen from dog excretes was provided by Dr Nick Costa of Murdoch University (cited in Water and Rivers Commission, 1998, *Technical Report on Kennel Waste Disposal and Management for Public Drinking Water Source Areas, Jandakot Groundwater Protection Policy area,* Water and Rivers Commission, Water Resource Protection Series No WRP 29). The estimation is based on the nitrogen content of typical dog foods and the digestibility of nitrogen in a dog's system as shown below.

Average dog = 20 kg

Consumes approximately	= 240 g dry food d^{-1}
	= 60 g protein d^{-1} (25%)
	= 9.6 g N d^{-1} (16%)
80% of total is digestible	= 7.68 g N d^{-1}
Faeces	= 1.92 g N d^{-1} (20%)
Urine approximately	= 2 g urea 100 $^{-mL}$
	= 300 mL d^{-1}
	= 6 g urea d^{-1}
	= 2.67 g N d^{-1} (44.5%)

Total waste = 4.59 g N d^{-1}

Small dog or cat = 4 kg

Faeces = 0.52 g N d^{-1}

Urine = 0.71 g N d^{-1}

Total waste = 1.23 g N d^{-1}

Large dog = 60 kg

Faeces = 4.30 g N d^{-1}

Urine = 6.04 g N d^{-1}

Total waste = 10.34 g N d^{-1}

3.4.3 Estimated Phosphorus Output From Dogs

The amount of phosphorus from dog excretes was estimated in the same method as amount of nitrogen above- mentioned.

Average dog = 20 kg

Consumes approximately = 240 g dry food d^{-1}

80% of total is digestible = 192 g dry food d^{-1}

Faeces = 48 g dry food d^{-1} (20%)

Urine approximately = 300 mL d^{-1}

= 300 g d^{-1}

The faeces contain about 0.25%phosphate and the urine contains about 0.01% P_2O_5

Total waste for average dog = Faeces + Urine

$= 48 + 300$ g/d

$= (48\times0.0025) + (300\times0.0001)$ g P d^{-1}

$= 0.12 + .03$ g d^{-1}

$= 0.15$ g P d^{-1}

Small dog or cat = 4 kg

Faeces = 9.6 g d^{-1}

Urine = 60 g d^{-1}

Total waste for average small dog = Faeces + Urine

$= 9.6 + 60$ g d^{-1}

$= (9.6\times0.0025) + (60\times0.0001)$ g P d^{-1}

$= 0.024 + 0.006$ g P d^{-1}

$= 0.030$ g P d^{-1}

Large dog = 60 kg

Faeces = *144 g d^{-1}*

Urine = *900 g d^{-1}*

Total waste for average large dog = Faeces + Urine

$= 144 + 900$ g d^{-1}

$= (144\times0.0025) + (900\times0.0001)$ g P d^{-1}

$= 0.36 + 0.09$ g P d^{-1}

$= 0.45 \text{ g P d}^{-1}$

The surveys indicated that the average number of dogs per property was usually half of the maximum number of dogs. Therefore amount of nitrogen and phosphorus used to estimate the nutrient input load from dog represents average dog in this study.

3.4.4 Pet Waste Estimation

At Wanneroo

Dog

Number of houses	= 203 houses
Ave of dog per house	= 0.72 dog
Amount of Nitrogen excretes	= 4.5 $\text{g N d}^{-1}\text{ dog}^{-1}$
Amount of Phosphorus excretes	= 0.15 $\text{g P d}^{-1}\text{ dog}^{-1}$
% contribution of pet waste disposal in G&L	= 30 percent
TN input from dog waste	= (203×0.72×4.5×30)/100
	= 198 $\text{g N d}^{-1}\text{ catchment}^{-1}$
	= 5945 $\text{g N 30 d}^{-1}\text{ catchment}^{-1}$
	= 6143 $\text{g N 31 d}^{-1}\text{ catchment}^{-1}$
Ave amount Of TN input from dog waste	= 6044 $\text{g N month}^{-1}\text{ catchment}^{-1}$
	= 6.04 $\text{kg N month}^{-1}\text{ catchment}^{-1}$
TP input from dog waste	= (203×0.72×0.15×30)/100
	= 6.61 $\text{g P d}^{-1}\text{ catchment}^{-1}$

$= 198$ g P 30 d^{-1} catchment^{-1}

$= 205$ g P 31 d^{-1} catchment^{-1}

Ave amount Of TP input from dog waste $= 201$ g P month^{-1} catchment^{-1}

$= 0.20$ kg P month^{-1} catchment^{-1}

Cat

Number of houses $= 203$ houses

Ave of cat per house $= 0.6$ cat

Amount of Nitrogen excretes $= 1.23$ g N d^{-1} cat^{-1}

Amount of Phosphorus excretes $= 0.03$ g P d^{-1} cat^{-1}

% contribution of pet waste disposal in G&L= 26 percent

TN input from cat waste $= (203\times0.6\times1.23\times26)/100$

$= 39$ g N d^{-1} catchment^{-1}

$= 1170$ g N 30 d^{-1} catchment^{-1}

$= 1209$ g N 31 d^{-1} catchment^{-1}

Ave amount of TN input from cat waste $= 1190$ g N month^{-1} catchment^{-1}

$= 1.20$ kg N month^{-1} catchment^{-1}

TP input from cat waste $= (203\times0.6\times0.03\times26)/100$

$= 0.96$ g P d^{-1} catchment^{-1}

$= 29$ g P 30 d^{-1} catchment^{-1}

= 30 g P 31 d^{-1} $catchment^{-1}$

Ave amount Of TP input from cat waste = 29 g P $month^{-1}$ $catchment^{-1}$

= 0.029 kg P $month^{-1}$ $catchment^{-1}$

At Bannister Creek

Dog

Number of houses = 799 houses

Ave of dog per house = 0.69 dog

Amount of Nitrogen excretes = 4.5 g N d^{-1} dog^{-1}

Amount of Phosphorus excretes = 0.15 g P d dog^{-1}

% contribution of pet waste disposal in G&L = 23 percentage

N input from dog waste = (799×0.69×4.5×23) / 100

= 559 g N d^{-1} $catchment^{-1}$

= 16779 g N 30 d^{-1} $catchment^{-1}$

= 17338 g N 31 d^{-1} $catchment^{-1}$

Ave amount Of TN input from dog waste = 17059 g N $month^{-1}$ $catchment^{-1}$

= 17.06 kg N $month^{-1}$ $catchment^{-1}$

TP input from dog waste = (799×0.69×0.15×23)/100

= 19 g P/d/catchment

= 570 g P/30 d/catchment

= 589 g P/31 d/catchment

Ave amount Of TP input from dog waste = 579 g P/month/ catchment

= 0.58 kg P/month/ catchment

Cat

Number of houses = 799 houses

Ave of cat per house = 0.46 cat

Amount of Nitrogen excretes = 1.23 g N/d/cat

Amount of Phosphorus excretes = 0.03 g P/d/cat

% contribution of pet waste disposal in G&L = 18 percent

TN input from cat waste = (799×0.46×1.23×18)/100

= 81 g N d^{-1} $catchment^{-1}$

= 2401 g N 30 d^{-1} $catchment^{-1}$

= 2481 g N 31 d^{-1} $catchment^{-1}$

Ave amount of TN input from cat waste = 2441 g N $month^{-1}$ $catchment^{-1}$

= 2.44. kg N $month^{-1}$ $catchment^{-1}$

TP input from cat waste = (799×0.46×0.03×18)/100

= 1.95 g P d^{-1} $catchment^{-1}$

= 58.57 g P 30 d^{-1} $catchment^{-1}$

$= 61$ g P 31 d^{-1} $catchment^{-1}$

Ave amount Of TP input from cat waste $= 60$ g P $month^{-1}$ $catchment^{-1}$

$= 0.06$ kg P $month^{-1}catchment^{-1}$

Other pets found in the study sites were birds, chickens, guinea pigs, fishes and rabbits. When their amounts and sizes were taken into consideration in relative to the amounts and sizes of dogs and cats, they should produce wastes lower than dogs and cats and even less if their wastes were compared to the amounts of fertiliser used in the study sites themselves. Therefore the other pet wastes were excluded from pet waste estimation in this study.

APPENDIX 3.5 ESTIMATION OF NUTRIENT INPUT LOAD FROM RAINWATER

Nutrient input load from rainwater can be estimated by multiplying the concentration of nutrients in rainwater and the volume of rainwater pouring into the catchment.

3.5.1 Rainwater Concentration

Rainwater concentration can be acquired from conducting chemical analysis of nutrients in the laboratory by the methods described in APHA (1998). Rainwater concentration in this estimation was acquired from the average of nutrient concentration of all rainwater samples collected during the sample period.

3.5.2 Rainwater Volume

Rainwater volume in this study can be calculated by multiplying the rain fall level in metre and area of the study site in square metre. Therefore amount of rainwater should be in cubic metre.

3.5.3 Nutrient Input Load from Rainwater

Nutrient input load from rainwater equalled to the multiplication between rainwater concentration and its volume.

3.5.4 Example of Estimation of Nutrient Input load

At Wanneroo (on October,02)

Rainfall level = 0.0138+0.0039+0.0030+0.034+0.002 m

= 0.057 m

Area of study site = 197376 m^2

TN concentration of rainwater = 268 mg m^{-3}

TP concentration of rainwater = 21 mg m^{-3}

TN input from rainwater = $0.057 \times 197376 \times 268$

= 3015116 mg

= 3015 g

= 3.02 kg

TP input from rainwater = $0.057 \times 197376 \times 22$

= 247509 mg

= 248 g

= 0.25 kg

At Bannister Creek (on October,02)

Rainfall level = 14.6+8.2+1.2+0.2+1.5+0.4+3.8+0.4+3.6 mm

= 47.4 mm

= 0.0474 m

Area of study site = 999950 m^2

TN concentration of rainwater = 268 mg m^{-3}

TP concentration of rainwater = 22 mg m^{-3}

TN input from rainwater = $0.047 \times 999950 \times 268$ mg

= 12595370 mg

= 12595 g

$= 12.60 \text{ kg}$

TP input from rainwater $= 0.0474 \times 999950 \times 22$

$= 1042748 \text{ mg}$

$= 1043 \text{ g}$

$= 1.04 \text{ kg}$

APPENDIX 3.6 ESTIMATION OF NOx INPUT LOADS FROM VEHICLE EXHAUST

3.6.1 Wind rose Contribution Factor

Wind rose contribution factor is created by using wind speed and wind direction sector percentage collected by the Department of Environmental Protection from the base stations which is the nearest to the study sites during the period: 01/Jun/ 2002 to 31/May/ 2003 inclusive.(See appendix: showing wind rose at Cullacabardee and South Lake station).

At Wanneroo study site, the data at Cullacabardee M.S. station from Department of Environmental Protection were applied by summation of those values in wind directions from the N, NNE, NE, ENE, E, ESE, SE, SSE, and NNW

At Bannister creek study site, the data at South Lake A.Q. M. S. station from Department of Environment were applied by summation of those values in wind directions from the N, NNE, NE, ENE, E, ESE, SE, NW, and NNW

Wanneroo study site: Cullacabardee = Wind rose - Calms (Less than 0.5ms^{-1})

= 48.6 - 3.2 %

= 45.4 %

Bannister creek study site: South Lake = Wind rose - Calms (Less than 0.5 ms^{-1})

= 45.2 - 3.5 %

= 41.7 %

3.6.2 Traffic Volume

At Wanneroo in 2001:

Site Names: 6618, Wanneroo Rd, N of Joondalup Dr (5-10 / Oct / 01)

Ave M – S = 15209 Vehicles d^{-1}

Àve M – S / N – S = 7590 – 7575 Vehicles d^{-1}

Site Names: 6392, Wanneroo Rd, S of Dundebar Rd (5-10 / Oct / 01)

Ave M – S = 18279 Vehicles d^{-1}

Àve M – S / N – S = 8828 – 9416 Vehicles d^{-1}

Site Names: 1945, Wanneroo Rd, N of Pinjar Rd (5-10 / Oct / 01)

Ave M – S = 17580 Vehicles d^{-1}

Àve M – S / N – S = 9685 – 7856 Vehicles d^{-1}

Ave M-S = 15209 + 7590 + 7575 + 18279 + 8828 + 9416 + 17580 + 9685 + 7856 = 102018/9 = 11335.33 = 11350 Vehicles d^{-1}

At Wanneroo in 2003:

Site Names: 4071, Wanneroo Rd, N of Ocean Reef Rd (25-28 / Aug / 03)

Ave M – F = 37699 Vehicles d^{-1}

Àve M – F / N – S = 18404 – 19295 Vehicles d^{-1}

Site Names: 1945, Wanneroo Rd, N of Pinjar Rd (20-25 / Aug , 2-5 / Sep / 03)

Ave M – S = 9225 Vehicles d^{-1}

Site Names: 6410, Wanneroo Rd, N of Dundebar Rd (25-28 / Aug / 03)

Ave M – F = 25619 Vehicles d^{-1}

Àve M –F / N – S = 12629 – 12990 Vehicles d^{-1}

Site Names: 6392, Wanneroo Rd, S of Dundebar Rd (25-28 / Aug / 03)

Ave M – F = 22166 Vehicles d^{-1}

Àve M – F / N – S = 10504 – 11662 Vehicles d^{-1}

2003 Ave M – F = 37699 + 18404 + 19295 + 9225 + 25619 + 12629 + 12990 + 22166 + 10504 + 11662 = 180193 / 10 = 18019.3 Vehicles d^{-1}

Average of traffic volume at Wanneroo study site between 2001 and 2003 is equal to

= 11350 + 18000 = 29350/2 = 14675 = 14600 Vehicles d^{-1}

At Bannister Creek in 2001

Site Names: 2936, High Rd, E of Leach Hwy (12-15 / Jun / 01)

Àve M – F / E – W = 9514 – 9854 Vehicles d^{-1}

Site Names: 4712, High Rd, E of Vahland Ave (12-15 / Jun / 01)

Ave M – F = 25140 Vehicles d^{-1}

Ave M – F / E = W = 12296 – 12817 Vehicles d^{-1}

Site Names: 4711, High Rd, W of Vahland Ave (12-15 / Jun / 01)

Ave M – F = 22602 Vehicles d^{-1}

Àve M –F / E – W = 10975 – 11597 Vehicles d^{-1}

Site Names: 5239, High Rd, W of Nicholson Rd (12-15 / Jun / 01)

Ave M – F = 13784 Vehicles d^{-1}

Àve M – F / E –W = 6975 – 6774 Vehicles d^{-1}

Site Names: 0232, High Rd, E of Riley Rd (12-15 / Jun / 01)

Ave M – F = 21614 Vehicles d^{-1}

Àve M – F / E –W = 10426 – 11154 Vehicles d^{-1}

2001 Ave M – F = 9514 + 9854 + 25140 + 12296 + 12817 + 22602 + 10975 + 11597 + 13784 + 6975 + 6774 + 21614 + 10426 + 11154 = 185522/14 = 13251.57143 = 13250 Vehicles d^{-1}

At Bannister Creek in 2002

Site Names: 2936, High Rd, E of Leach Hwy (21-26 / Aug / 02)

Àve M – S / E – W = 7427 – 9970 Vehicles d^{-1}

Site Names: 4712, High Rd, E of Vahland Ave (21-26 / Aug / 02)

Ave M – S = 23832 Vehicles d^{-1}

Ave M – S / E = W = 12676 – 11105 Vehicles d^{-1}

Site Names: 4711, High Rd, W of Vahland Ave (21-26 / Aug / 02)

Ave M – S = 21983 Vehicles d^{-1}

Àve M –S / E – W = 10987 – 10958 Vehicles d^{-1}

2002 Ave M – S = 7427 + 9970 + 23832 + 12676 + 11105 + 21983 + 10987 + 10958 = 108938 / 8 = 13617.25 = 13600 Vehicles d^{-1}

At Bannister Creek in 2003

Site Names: 4154, Vahland Ave, S of High Rd (28/Apr-01/May / 03)

Ave M – F = 17855 Vehicles d^{-1}

Ave M – F / N - S = 9132 – 8692 Vehicles d^{-1}

Site Names: 4729, Metcalfe Rd, N of High Rd (22-28 / Apr / 03)

Ave M – S = 11517 Vehicles d^{-1}

Àve M –S / N – S = 5814 – 5655 Vehicles d^{-1}

2003 Ave M – ES = 17855 + 9132 + 8692 + 11517 + 5814 + 5655 = 58665/6 = 9777.5 = 9800 Vehicles d^{-1}

Average of traffic volume at Bannister creek study site between 2001 and 2002 is equal to = 13250 + 13600 = 13425 Vehicles d^{-1}

3.6.3 Vehicle Classification

Vehicle Classification is based on "AUSTROADS '94 Vehicle Classification System" and conducted by Main Roads Western Australia.

At Wanneroo

Site ID: 50941.ON

Location: Wanneroo Rd, S of Beach Rd 50 – 388549 - 6476018

Filter time 12.23 p.m. 10 / Jun - 10.53 a.m. 13 / Jun / 03

C1(89.7) C2(2.5) C3(2.8) C4(0.8) C5(0.6) C6(0.1) C7(1.8) C8(0.2) C9(1) C10 (0.1) C11(0.3) C12(0.1)

Site ID: 50943 OS

Location: Wanneroo Rd, S of Beach Rd 50 – 388561 – 6476020

Filter time 12.24 p.m. 10 / Jun - 10.50 a.m. 13 / Jun / 03

C1(88.5) C2(3) C3(2.6) C4(0.8) C5(0.6) C6(0.1) C7(2.5) C8(0.2) C9(1) C10 (0.1) C11(0.3) C12(0.2)

Average of vehicle classification of two Sites at Wanneroo study site is equal to

C1(89.1) C2(2.75) C3(2.7) C4(0.8) C5(0.6) C6(0.1) C7(2.2) C8(0.2) C9(1) C10 (0.1) C11(0.3) C12(0.2)

At Bannister Creek

Site ID: 47282.OE

Location: High Rd, VW of Metcalfe Rd 50 – 397616 - 6454514

Filter time 12.37 p.m. 24 / Nov - 11.58 a.m. 2 / Dec / 03

C1(93.8) C2(2.2) C3(1.6) C4(0.5) C5(0.2) C6(0.2) C7(1.0) C8(0.1) C9(0.4) C10 (0.0) C11(0.1) C12(0.0)

C1(92.9) C2(2.3) C3(2.2) C4(0.4) C5(0.2) C6(0.2) C7(0.9) C8(0.1) C9(0.5) C10 (0.0) C11(0.1) C12(0.1)

At Bannister Creek

Site ID: 47284.ZW

Location: High Rd, W of Metcalfe Rd 50 – 397618 - 6454505

Filter time 12.40 p.m. 24 / Nov - 12.05 p.m. 2 / Dec / 03

C1(92.8) C2(2.3) C3(1.5) C4(0.4) C5(0.4) C6(0.1) C7(1.6) C8(0.1) C9(0.5) C10 (0.1) C11(0.1) C12(0.1)

C1(91.3) C2(2.5) C3(2.0) C4(0.5) C5(0.5) C6(0.2) C7(1.7) C8(0.1) C9(0.8) C10 (0.1) C11(0.2) C12(0.1)

Average of vehicle classification of two Sites at Bannister creek study site is equal to

C1(92.7) C2(2.3) C3(1.8) C4(0.5) C5(0.3) C6(0.2) C7(1.3) C8(0.1) C9(0.6) C10 (0.1) C11(0.1) C12(0.1)

3.6.4 NOx Emission Rate

The amount of pollution generated by some different types of vehicles is taken from techniques used to estimate the emissions from vehicles for the National Pollutant Inventory (see **www.npi.gov.au** for more information on NPI)

All emission rates below are given in grams per kilometre travelled.

	CO	NOx	VOCs	VOCs	PM10
Petrol car (4, 6 or 8 cyl)	22.3	1.78	1.45	0.535	0.00932
LPG car (4, 6 or 8 cyl)	27.9	1.23	1.73	1.07	0.00329
Petrol ute/van/4WD	30.6	1.73	2.53	0.586	0.0118
Diesel ute/van/4WD	1.44	1.35	0.857		0.222
Diesel truck	7.87	8.73	1.56		0. 584
Petrol motorcycle	16.1	0.558	1.9	0.803	0.0124

CO = carbon monoxide; NOx = oxides of nitrogen; VOCs = volatile organic compounds (such as petrol vapours); PM10 = particles

Based on this information, all vehicles classified as class C1 and C2 are assumed to produce the NOx rate 1.5225 g km^{-1}. This figure is acquired from the average rate of NOx produced by petrol car, LPG car, petrol ute/van/4WD and Diesel ute/van/4WD which equal to 1.78,1.23, 1.73 and 1.35g km^{-1} respectively. Vice versa, all vehicle classified as class C3 to C12 are assumed to produce the NOx rate 8.73 g km^{-1}. because they are all heavy vehicles which classified as trucks.

At Wanneroo

The distance the traffic volume passed by the Wanneroo study site is approximately 600 metres. This figure is acquired from measuring the distance the traffic volume passed by and then scaling with ratio provided on the Perth Street Directory. Therefore the amount of NOx produced by car and truck equal to 0.9135 g 600 m^{-1} and 5.238 g 600 m^{-1} respectively.

At Bannister Creek

The distance the traffic volume passed by the Bannister Creek study site is approximately 400 metres. This figure is acquired from measuring the distance the traffic volume passed by and then scaling with ratio provided on the Perth Street Directory. Therefore the amount of NOx produced by car and truck equal to 0.609 g 400 m^{-1} and 3.492 g 400 m^{-1} respectively.

3.6.5 Estimation of NOx Input Loads

At Wanneroo

Wind rose = 45.4 %

Traffic volume = 14600 Vehicles d^{-1}

Vehicle Classification

C1 - C2 = 91.8 %

C3 – C12 = 8.2 %

NOx emission rate

C1 – C2 $\quad = 0.9135$ g vehicle^{-1}

C3 – C12 $\quad = 5.238$ g vehicle^{-1}

Vehicle classification

Number of vehicles in class C1 and C2 $= 14{,}600\times91.8 / 100$

$= 13{,}402.8$ vehicles

Number of vehicles in class C3 up to C12 $= 14{,}600\times8.2 / 100$

$= 1197.2$ vehicles

Amount of NOx produced from traffic volume in Wanneroo study site equalled to

= Amount of car × NOx emission rate

$= (13043\times0.9135) + (1197\times5.238)$

$= 12243.6405 + 6269.886$

$= 18513.53$ g d^{-1}

Wind rose contribution factor is taken into consideration to adjust the real amount of total input of NOx loads entering to the study area. Therefore the real amount of NOx input load entering the study area is equal to

$= 18513.53 \times 45.4\% = 18513.53\times45.4/100 = 8405.14$ g d^{-1}

$= 8.4$ kg d^{-1}

$= 252$ kg month^{-1}

At Bannister Creek

Wind rose $\quad = 41.7$ %

Traffic volume = 13,425 Vehicles d^{-1}

Vehicle Classification

C1 - C2 = 95 %

C3 – C12 = 5 %

NOx emission rate

C1 – C2 = 0.609 g vehicle $^{-1}$

C3 – C12 = 3.492 g vehicle^{-1}

Vehicle classification

Number of vehicles in class C1 and C2 $= 13{,}425 \times 95 / 100$

$= 12{,}753.75$ vehicles

Number of vehicles in class C3 up to C12 $= 13{,}425 \times 5 / 100$

$= 671.25$ vehicles

Amount of NOx produced from traffic volume in Wanneroo study site equalled to

= Amount of car × NOx emission rate

$= (12{,}754 \times 0.609) + (671 \times 3.492)$

$= 7767.186 + 2343.132$

$= 10110.318$ g d^{-1}

Wind rose contribution factor is taken into consideration to adjust the real amount of total input of NOx loads entering to the study area. Therefore the real amount of NOx input load entering the study area is equal to

$= 10110.318 \times 41.7\% = 10110.318 \times 41.7/100 = 4216.002606 \text{ g d}^{-1}$

$= 4.2 \text{ kg d}^{-1}$

$= 126 \text{ kg month}^{-1}$

APPENDIX 4 - OUTPUT LOAD ESTIMATION

APPENDIX 4.1 AT BANNISTER CREEK

4.1.1 Daily discharge at Bannister Creek was calculated using both the Manning equation and a runoff coefficient. This is because the water depth of the culvert was measured three times a week. The water depths were assumed to remain constant between sampling times. Rainfall during this intervening period was not included in the discharge. To attempt to include rainfall events, a runoff coefficient was introduced to estimate the amount of rainfall added to the discharge.

Discharge in the drain was determined by using equation 3.1 (below). At Bannister Creek, low flows prevented the use of propelled velocity meters and so velocity was estimated from the depth based on the Manning formula equation 3.2 (LMNO Engineering, 2004).

$Q = vA$ Equation 3.1

$v = k/n\ (2A/\theta d)^{2/3}\ S^{1/2}$ Equation 3.2

Derived from equations 3.3 to 3.7

$A = d^2/8\ (\theta - \mathrm{Sin}\theta)$ Equation 3.3

$R = A/P$ Equation 3.4

$P = \theta d / 2$ Equation 3.5

$\theta = 2\mathrm{Cos}^{-1}(1-2y/d)$ Equation 3.6

$v = k/n\ R^{2/3}\ S^{1/2}$ Equation 3.7

Where :

A = Cross-sectional area of the drain containing the discharge in m^2

d = Culvert diameter in m which was 1.20 m.

k = Unit conversion factor = 1.0

n = Manning coefficient. In this study, the culvert surface of both study sites was finished concrete which has an n value of 0.012.

P = Wetted perimeter in m. P is the contact length (in the cross-section) between the water and the culvert.

Q = Discharge or flow rate in $m^3\ s^{-1}$.

R = Hydraulic radius of the flow cross-section in m.

S = Slope of channel bottom or water surface. The slope of the drains was obtained from the City of Canning and the City of Wanneroo. At Bannister Creek the drain slope is 1 m over 104 m and at Wanneroo the drain slope is 1 m over 188 m. Therefore, the slopes for the Bannister Creek and Wanneroo sites were 0.0096 and 0.0053 respectively.

v = Velocity of the water in $m\ s^{-1}$

y = Water depth measured (perpendicular) to the bottom of the culvert in m.

As the culvert has a small slope (S), entering the vertical depth introduces only minimal error.

θ = Angle representing how full the culvert is in radians. A culvert with $\theta = 0$ radians (0^o) contains no water, a culvert with θ = pi radians (180^o) is half full, and a culvert with θ = 2 pi radians (360^o) is completely full.

The daily discharge was based on the water depth (y) in the culvert as measured in the regular sampling program. From this, θ was determined using equation 3.6, by substituting y and the culvert diameter (d). After that θ was substituted into equation 3.3 to determine the flow cross-sectional area (A). Equation 3.2 was then used to determine the velocity of the water (v). Discharge (equation 3.1) was then converted to daily discharge. For example the daily stormwater output load on 16 April, 2002.

$$\theta = 2\cos^{-1}(1-2y/d) \qquad \text{Equation 3.6}$$

If $y = 0.015$ m, and $d = 1.2$ m

Replace y and d in the Equation above

$\theta = 0.45$ radian

$A = d^2/8\ (\theta - \text{Sin}\theta)$ Equation 3.3

Replace $\theta = 0.45$ radian, d = 1.2 m

$A = (1.2)^2/8\ (0.45 - \text{Sin } 45)$

$A = 0.0027\ m^2$

$v = k/n\ (2A/\theta d)^{2/3}\ S^{1/2}$ Equation 3.2

Replace k = 1, n = 0.012, $A = 0.0027\ m^2$, and S = 0.0096

$v = 0.38\ m\ s^{-1}$

The daily discharge from the drain when there is no rain

$Q = vA$ Equation 3.1

Replace $v = 0.38\ m\ s^{-1}$, $A = 0.0027\ m^2$

$Q = 0.38 \times 0.0027\ m^3\ s^{-1} \times 24 \times 60 \times 60\ s^{-1}$

$Q = 87\ m^3\ d^{-1}$

4.1.2 The runoff discharge from the drain Q_R on the 16th April 2002

Runoff Coefficient is used to estimate the volume of water discharged from the culvert at each study site whenever it rains.

To find out this value, the velocities or the flow rates and the depths from the culvert were measured by the flow meter in Wanneroo city and by the depth sensor in Bannister creek (Canning city) respectively at different levels. As well as the times and the rainfall data were kept records since the rain started until it stopped during the storm event.

From field work during storm event, the velocities (flow rates) at different depth levels, the flow duration of each different depths and the rainfall data were recorded to use for evaluating the volume of water discharged from the culvert versus the volume of water accumulated in the small residential catchment.

What were known are the velocity (v) at each different depth (y), the flow duration of each depth (Time = t) and the rainfall data in mm during the storm event. From this point, θ can be calculated by using the equation $y = d/2(1-\text{Cos}\theta/2)$ and $\underline{\theta = 2\text{Cos}^{-1}(1-2y/d)}$. Then replace θ in equation $A = d^2/8\ (\theta - \text{Sin}\theta)$ and equation $v = \underline{k/n\ (2A/\theta d)^{2/3}\ S^{1/2}}$. In this case d and S known from measurement ; θ, k and A, known from calculation; and n from Manning's n Coefficients; all values are replaced in equations mentioned above to find out θ, A, and v respectively. Ultimately the volume of the water discharged from (Q1) and accumulated in (Q2) the small residential catchment can be calculated through these formulars Q1 = v * A1 (Flow cross-sectional area)*t and Q2 = A2 (Catchment area)*rainfall depth respectively. The runoff coefficient is defined as the volume of the water discharged from the residential catchment (Q1) versus the volume of the water accumulated in the residential catchment (Q2). In this study, runoff coefficients at Wanneroo city and Bannister creek (Canning city) are equal 0.305031428 and 0.250933944 respectively.

The runoff coefficient was determined by using the depth sensor (installed adjacent to the culvert between 19 August 2002 and 11 December 2002) which recorded the water depth at 10 minute intervals (Figure 3.2). The depth sensor measurements were converted to match the other depth data. A linear regression of depth sensor vs measured depth was produced ($y = 0.085x - 12.57$; $r^2 = 0.868$) and used to adjust the depth sensor measurements. A series of discrete storm events were identified from the sensor data and matched to rainfall data (provided by Sandra Hall, postgraduate student, who had installed a continuous rain gauge near the study site).

The runoff discharge from the drain Q_R on the 16th April 2002

Q_R = Catchment Area × rainfall × runoff coefficient

Replace catchment area = 999950 m^2, rainfall = 0.056 m d^{-1} runoff coefficient = 0.25

$Q_R = 14102\ m^3\ d^{-1}$

4.1.3 Output Load Estimation

The Bannister Creek site includes groundwater flow. To quantify the output load from stormwater alone at this study site, the groundwater flow load was taken into consideration. In this case, the output load (L_O) was equal to the total output load (L_T) minus the groundwater flow load (L_{GW}).

$L_O = L_T - L_{GW}$ Equation 3.8

L_T was determined by multiplying the total daily discharge (the daily discharge when there is no rain and the runoff discharge when there is rain) by the measured nutrient concentration. Nutrient concentrations for those days when samples were not collected were assumed to be the same as the previous concentration measured. Therefore, this assumes that the concentration from a single grab sample is representative of nutrient concentrations during the intervening period.

The total output load (L_T) estimation on the 16th April 2002

$L_T = (Q + Q_R) \times$ TN concentration

$L_T = (87 + 14102)\ m^3\ d^{-1} \times 1345\ mg\ m^3$

$L_T = 117400 + 18972466\ mg\ d^{-1}$

$L_T = 19089866\ mg\ d^{-1}$

L_{GW} was estimated by multiplying flows on days of no rainfall (assuming base flow conditions) with the average nutrient concentration of the base flow during the summer period from December 2002-February 2003 (when there was no rain event).

L_{GW} = (base flow discharge × average nutrient concentration during summer)

$L_{GW} = (87m^3\ d^{-1} \times 1408\ mg\ m^3)$

$L_{GW} = 122849\ mg\ d^{-1}$

The output load estimation on the 16th April 2002

$L_O = L_T - L_{GW}$ Equation 3.8

$L_O = 19089866 - 122849$

$L_O = 18967017\ mg\ d^{-1}$

APPENDIX 4.2 AT WANNEROO

The Wanneroo site showed that there was no contribution to the stormwater drain from groundwater baseflow and the flow only occurs following sufficient rains. The load therefore simply varies with the volume of water discharged from the catchment over time and the concentration of nitrogen and phosphorus in the water. The output load is calculated by applying runoff coefficient method as mentioned above.

L_O = Catchment Area × rainfall × runoff coefficient × TN concentration

Replace catchment area = 197375 m^2, rainfall = 0.0004 m , runoff coefficient 0.132, TN concentration = 310.34 mg m^3

$$L_O = 3236 \text{ mg d}^{-1}$$

APPENDIX 5 - NUTRIENT BALANCE / MASS BALANCE OF NUTRIENT

5.1 Nutrient Balance

The nutrient balance at each study site is calculated by assuming that total nutrient output loads from stromwater drain minus total nutrient input loads from rainwater source via hard surface area of the catchment equals total nutrient input loads from non-point sources.

Base on the assumption mentioned above, the equation is as follows.

TN Output loads from stormwater drain (178.08 kg) – TN Input loads from rainwater source via hard surface area (9.54 kg) = TN Input loads from non-point sources (168.54 kg).

Month	TN nutrient balance at Bannister Creek study site (kg)		
	TN Input loads - rainwater source	TN Input loads – non-point sources	TN Output loads
Jun, 02	9.54	168.54	178.08
Jul,02	7.24	58.46	65.70
Aug,02	4.35	12.41	16.75
Sep,02	1.92	17.55	19.47
Oct,02	2.88	10.25	13.13
Nov,02	1.31	8.02	9.34
Dec,02	0.23	1.45	1.68
Jan,03	0.02	0.47	0.50
Feb,03	0.46	2.26	2.72
Mar,03	2.85	14.46	17.31
Apr,03	2.95	11.35	14.30
May,03	4.50	17.95	22.45
Total (kg/yr)	38.27	323.17	361.44
Range	0.024-9.54	0.47-168.53	0.49-178.08
Mean ± SE	3.19 ± 0.83	26.93 ± 13.60	30.12 ± 14.32
Median	2.87	11.88	15.53

5.2 Mass Balance of Nutrients

A mass balance of a nutrient or nutrient budget in an ecosystem is an attempt to account for the quantity of nutrient input loads (‘income’) to an ecosystem, and the quantity of nutrient output loads (‘losses’) from an ecosystem (Calow, 1999). Accumulation of total mass in a system is equal to the difference between input and output load.

5.2.1 Nitrogen

Although the mechanisms that might contribute to N retention in the catchment were not measured, they were modelled using the rate of nitrogen processes provided by Dr Christian Zammit (Department of Environment) for Bannister Creek. The rates for N processes were mineralisation (0.00001964 g m^{-2} d^{-1}), volatilisation (0.0004 g m^{-2} d^{-1}), nitrification (0.00284 g m^{-2} d^{-1}), denitrification (0.0124 g m^{-2} d^{-1}), plant uptake (0.1546 g m^{-2} d^{-1}), fixation (0.00294 g m^{-2} d^{-1}), surface entrainment (0.00101 g m^{-2} d^{-1}), and vertical entrainment or leaching (0.00153 g m^{-2} d^{-1}).

The values for nitrogen processes provided by Dr Christian Zammit and Professor William Stock are used in quantify of N and P in each pathway of mass balance of nutrients. These values were determine through the LArge Scale CAtchment Model (LASCAM) developed with the aim of predicting the impact of land use and

climatic changes on the daily trends of streamflow and water quality (salinity, sediments, nutrients, etc.) in large catchments over long time periods. The key elements of LASCAM are published in, Viney and Sivapalan (1999) and Viney et al. (2000).

The model predicts catchment export of diffuse-source soluble and particulate phosphorus, particulate nitrogen, nitrate-nitrogen and ammonium-nitrogen. It explicitly includes the nutrient cycling processes of sorption, mineralisation, leaching, fixation, volatilisation, nitrification, denitrification, plant uptake and harvest losses. Soluble nutrients are assumed to be mobilised by surface runoff and by baseflow discharge, while particulate nutrients are associated with surface erosion and the stream sediment transport processes of deposition, re-entrainment, bed degradation and settling. The nutrient model includes 29 optimisable parameters, 11 for phosphorus and 18 for nitrogen, although several of these can be prescribed from measurements or from the literature. The model is applied to two large subcatchments of the 120,000 km^2 Avon River basin in Western Australia and shown to provide good predictions of daily nutrient export in a long-term simulation.

Table 7.10 Processes, load and percentage of nitrogen at Bannister Creek(BC) and Wanneroo (WN).

Mass Balance	Quantity of Nitrogen (kg yr^{-1})		Percentage (%)	
	BC	WN	BC	WN
Total TN Input Load	5,912	4263		
Human Activities (Quest)	5,438	4,155		
Fixation	474	108		
Total TN Input Load	28249 (13107)	6345 (2903)		
Probability Load	28249 (13107)	6345 (2903)		
Total TN Storage	624	142	2.21 (4.76)	2.24 (4.89)
Mineralisation	3	1	0.01 (0.02)	0.01 (0.02)
Nitrification	458	104	1.62 (3.50)	1.64 (3.59)
Surface Entrainment	163	37	0.58 (1.24)	0.58 (1.28)
Total TN Output Load	27625 (12483)	6203 (2761)	97.79 (95.24)	97.76 (95.11)
TN output load from the drain	374	9	1.32 (2.85)	0.14 (0.30)
Plant uptake	24939 (9797)	5669 (2227)	88.28 (74.75)	89.34 (76.71)
Volatilisation	65	15	0.23 (0.49)	0.23 (0.51)
Denitrification	2000	455	7.08 (15.26)	7.17 (15.66)
Leaching	247	56	0.87 (1.88)	0.88 (1.93)

5.2.1.1 Total TN Input Load (Table 7.10)

Total TN Input Load from human activities (Quest) at Bannister Creek (5,438 kg yr^{-1}) and Wanneroo (4155 kg yr^{-1}) is derived from input load estimation of the questionnaires survey as shown in Table 4.8 and 4.9 respectively.

Fixation process

Total TN Input Load from fixation at Bannister Creek (474 kg yr^{-1}) and Wanneroo (108 kg yr^{-1}) is derived from the multiplying between the rate of fixation process (0.00294 g m^{-2} d^{-1}) and area of soft surface (lawn and garden) at Bannister Creek (441952 m^2) and at Wanneroo (100462 m^2) as shown below.

Total TN Input Load from fixation at Bannister Creek (474 kg yr^{-1})

= (0.00294 g m^{-2} d^{-1}) × (365 d) × (441952 m^2)

= 474258.6912 g

= 474 kg

Total TN Input Load from fixation at Wanneroo (108 kg yr^{-1})

= (0.00294 g m^{-2} d^{-1}) × (365 d) × (100462 m^2)

= 107805.7722 g

= 108 kg

Total TN Input Load (Probability Load) at Bannister Creek (28249 kg yr^{-1}) and Wanneroo (6345 kg yr^{-1}) is derived from summation of the total TN storage and the total TN output load as shown below.

Total TN Input Load (Probability Load) at Bannister Creek (28249 kg yr^{-1})

= (624 kg yr^{-1}) + (27625 kg yr^{-1})

= 28249 kg yr^{-1}

Total TN Input Load (Probability Load) at Wanneroo (6345 kg yr^{-1})

= (142 kg yr^{-1}) + (6203 kg yr^{-1})

= 6345 kg yr^{-1}

5.2.1.2 Total TN Storage (Table 7.10)

Total TN Storage at Bannister Creek (624 kg yr^{-1}) and Wanneroo (142 kg yr^{-1}) is derived from summation of mineralisation, nitrification, and surface entrainment, processes as shown below.

Total TN Storage at Bannister Creek (624 kg yr^{-1})

$= (3 \text{ kg yr}^{-1}) + (458 \text{ kg yr}^{-1}) + (163 \text{ kg yr}^{-1})$

$= 624 \text{ kg yr}^{-1}$

Total TN Storage at Wanneroo (142 kg yr^{-1})

$= (1 \text{ kg yr}^{-1}) + (104 \text{ kg yr}^{-1}) + (37 \text{ kg yr}^{-1})$

$= 142 \text{ kg yr}^{-1}$

Mineralisation

Total TN storage load from mineralisation at Bannister Creek (3 kg yr^{-1}) and Wanneroo (1 kg yr^{-1}) is derived from the multiplying between the rate of mineralization process (0.00001964 g m^{-2} d^{-1}) and area of soft surface (lawn and garden) at Bannister Creek (441952 m^2) and at Wanneroo (100462 m^2) as shown below.

Total TN storage load from mineralisation at Bannister Creek (3 kg yr^{-1})

$= (0.00001964 \text{ g m}^{-2} \text{ d}^{-1}) \times (365 \text{ d}) \times (441952 \text{ m}^2)$

$= 3168.177107 \text{ g}$

$= 3 \text{ kg}$

Total TN storage load from mineralisation at Wanneroo (1 kg yr^{-1})

$= (0.00001964 \text{ g m}^{-2} \text{ d}^{-1}) \times (365 \text{ d}) \times (100462 \text{ m}^2)$

$= 720.1718932$ g

$= 1$ kg

Nitrification

Total TN storage load from nitrification at Bannister Creek (458 kg yr^{-1}) and Wanneroo (104 kg yr^{-1}) is derived from the multiplying between the rate of nitrification process (0.00284 g m^{-2} d^{-1}) and area of soft surface (lawn and garden) at Bannister Creek (441952 m^2) and at Wanneroo (100462 m^2) as shown below.

Total TN storage load from nitrification at Bannister Creek (458 kg yr^{-1})

$= (0.00284 \text{ g m}^{-2} \text{ d}^{-1}) \times (365 \text{ d}) \times (441952 \text{ m}^2)$

$= 458127.4432$ g

$= 458$ kg

Total TN storage load from mineralisation at Wanneroo (104 kg yr^{-1})

$= (0.00284 \text{ g m}^{-2} \text{ d}^{-1}) \times (365 \text{ d}) \times (100462 \text{ m}^2)$

$= 104138.9092$ g

$= 104$ kg

Surface Entrainment

Total TN storage load from surface entrainment at Bannister Creek (163 kg yr^{-1}) and Wanneroo (37 kg yr^{-1}) is derived from the multiplying between the rate of surface entrainment process (0.00101 g m^{-2} d^{-1}) and area of soft surface (lawn and garden) at Bannister Creek (441952 m^2) and at Wanneroo (100462 m^2) as shown below.

Total TN storage load from surface entrainment at Bannister Creek (163kg yr^{-1})

$= (0.00101\ g\ m^{-2}\ d^{-1}) \times (365\ d) \times (441952\ m^2)$

$= 162925.6048\ g$

$= 163\ kg$

Total TN storage load from surface entrainment at Wanneroo (37 kg yr^{-1})

$= (0.00101\ g\ m^{-2}\ d^{-1}) \times (365\ d) \times (100462\ m^2)$

$= 37035.3163\ g$

$= 37\ kg$

5.2.1.3 Total TN Output Load (Table 7.10)

Total TN output load at Bannister Creek (27625 kg yr^{-1}) and Wanneroo (6203 kg yr^{-1}) is derived from summation of TN output load from the drain, plant uptake, volatilisation, denitrification and leaching processes as shown below.

Total TN output load at Bannister Creek (27625 kg yr^{-1})

$= (374\ kg\ yr^{-1}) + (24939\ kg\ yr^{-1}) + (65\ kg\ yr^{-1}) + (2000\ kg\ yr^{-1}) + (247\ kg\ yr^{-1})$

$= 27625\ kg\ yr^{-1}$

Total TN output load at Wanneroo (6203 kg yr^{-1})

$= (9\ kg\ yr^{-1}) + (5669\ kg\ yr^{-1}) + (15\ kg\ yr^{-1}) + (455\ kg\ yr^{-1}) + (56\ kg\ yr^{-1})$

$= 6203\ kg\ yr^{-1}$

TN output load from the drain at Bannister Creek (374 kg yr^{-1}) and Wanneroo (9 kg yr^{-1}) is derived from annual nutrient output load estimation as shown in Table 5.10.

Plant uptake

Dr. Christian Zammit's information

TN output load from plant uptake at Bannister Creek (24939 kg yr^{-1}) and Wanneroo (5669 kg yr^{-1}) is derived from the multiplying between the rate of plant uptake process (0.1546 g m^{-2} d^{-1}) and area of soft surface (lawn and garden) at Bannister Creek (441952 m^2) and at Wanneroo (100462 m^2) as shown below.

TN output load from plant uptake at Bannister Creek (24939 kg yr^{-1})

$= (0.1546 \text{ g m}^{-2} \text{ d}^{-1}) \times (365 \text{ d}) \times (441952 \text{ m}^2)$

$= 24938909.41$ g

$= 24939$ kg

TN output load from plant uptake at Wanneroo (5669 kg yr^{-1})

$= (0.1546 \text{ g m}^{-2} \text{ d}^{-1}) \times (365 \text{ d}) \times (100462 \text{ m}^2)$

$= 5668970.198$ g

$= 5669$ kg

Professor William Stock's information

TN output load from plant uptake at Bannister Creek (9797 kg yr^{-1}) and Wanneroo (2227 kg yr^{-1}) is derived from information based on Professor William Stock as shown in below.

"Lawn is determined approximately 300-400 g m^{-2} (as dry weight), N varies from 1-4% of N let say approximately 2% of N in average and P varies from 0.1-0.4% P let say approximately 0.2 % P. Whereas shrubby is determined approximately 3.5 kg m^{-2} (as dry weight), N is assumed to be equal to 1.5% and P is assumed to be equal to 0.15%."

Based on assumption mentioned above

TN output load from plant uptake at Bannister Creek (9797 kg yr^{-1})

Soft area in Bannister Creek is equal to 441952 m^2. This soft area is assumed to be divided into lawn area approximately 294635 m^2 (2/3) and garden area approximately 147317 m^2 (1/3).

Base on "Lawn is determined approximately 300-400 g m^{-2} yr^{-1} (as dry weight),and shrubby is determined approximately 3.5 kg m^{-2} yr^{-1} (as dry weight)"

Lawn = (294635m^2 × 300 g m^{-2} yr^{-1}) and (294635m^2 × 400 g m^{-2} yr^{-1})

= 88390400 g $catchment^{-1}$ yr^{-1} and 117853866.7 g $catchment^{-1}$ yr^{-1}

N varies from 1-4% of N let say approximately 2% of N in average

N composition in lawn = (88390400 × 2/100 g $catchment^{-1}$ yr^{-1}) and

= (117853866.7 × 2/100 g $catchment^{-1}$ yr^{-1})

= 1767808 g $catchment^{-1}$ yr^{-1} and 2357077 g $catchment^{-1}$ yr^{-1}

= 1768 kg $catchment^{-1}$ yr^{-1} and 2357 kg $catchment^{-1}$ yr^{-1}

= 2062 kg $catchment^{-1}$ yr^{-1} in average

Garden = (147317m^2 × 3.5 kg m^{-2} yr^{-1})

= 515611 kg $catchment^{-1}$ yr^{-1}

N is assumed to be equal to 1.5% for shrubby in the garden

N composition in garden = (515611 × 1.5/100 kg $catchment^{-1}$ yr^{-1}

= 7734 kg $catchment^{-1}$ yr^{-1}

Total Nitrogen from plant uptake in Lawn&Garden = 2062 + 7734 kg catchment^{-1} yr^{-1}

= 9797 kg catchment^{-1} yr^{-1}

TN output load from plant uptake at Wanneroo (2227 kg yr^{-1})

Soft area in Wanneroo is equal to 100462 m^2. This soft area is assumed to be divided into lawn area approximately 66975 m^2 (2/3) and garden area approximately 33487 m^2 (1/3).

Base on "Lawn is determined approximately 300-400 g m^{-2} yr^{-1} (as dry weight),and shrubby is determined approximately 3.5 kg m^{-2} yr^{-1} (as dry weight)"

Lawn = (66975m^2 × 300 g m^{-2} yr^{-1}) and (66975m^2 × 400 g m^{-2} yr^{-1})

= 20092400 g catchment^{-1} yr^{-1} and 26789866.67 g catchment^{-1} yr^{-1}

N varies from 1-4% of N let say approximately 2% of N in average

N composition in lawn = (20092400 × 2/100 g catchment^{-1} yr^{-1}) and

= (26789866.67 × 2/100 g catchment^{-1} yr^{-1})

= 401848 g catchment^{-1} yr^{-1} and 535797.33 g catchment^{-1} yr^{-1}

= 402 kg catchment^{-1} yr^{-1} and 536 kg catchment^{-1} yr^{-1}

= 469 kg catchment^{-1} yr^{-1} in average

Garden = (33487m^2 × 3.5 kg m^{-2} yr^{-1})

= 117206 kg catchment^{-1} yr^{-1}

N is assumed to be equal to 1.5% for shrubby in the garden

N composition in garden = (117206 × 1.5/100 kg catchment^{-1} yr^{-1}

$= 1758$ kg catchment^{-1} yr^{-1}

Total Nitrogen from plant uptake in Lawn&Garden = 469 + 1758 kg catchment^{-1} yr^{-1}

$= 2227$ kg catchment^{-1} yr^{-1}

Volatilisation

TN output load from volatilisation at Bannister Creek (65 kg yr^{-1}) and Wanneroo (15 kg yr^{-1}) is derived from the multiplying between the rate of volatilisation process (0.0004 g m^{-2} d^{-1}) and area of soft surface (lawn and garden) at Bannister Creek (441952 m^2) and at Wanneroo (100462 m^2) as shown below.

TN output load from volatilisation at Bannister Creek (65 kg yr^{-1})

$= (0.0004 \text{ g m}^{-2} \text{ d}^{-1}) \times (365 \text{ d}) \times (441952 \text{ m}^2)$

$= 64524.992$ g

$= 65$ kg

TN output load from volatilisation at Wanneroo (15 kg yr^{-1})

$= (0.0004 \text{ g m}^{-2} \text{ d}^{-1}) \times (365 \text{ d}) \times (100462 \text{ m}^2)$

$= 14667.452$g

$= 15$ kg

Denitrification

TN output load from denitrification at Bannister Creek (2000 kg yr^{-1}) and Wanneroo (455 kg yr^{-1}) is derived from the multiplying between the rate of denitrification process (0.0124 g m^{-2} d^{-1}) and area of soft surface (lawn and garden) at Bannister Creek (441952 m^2) and at Wanneroo (100462 m^2) as shown below.

TN output load from denitrification at Bannister Creek (2000 kg yr^{-1})

= (0.0124 g m^{-2} d^{-1}) × (365 d) × (441952 m^2)

= 2000274.752 g

= 2000 kg

TN output load from denitrification at Wanneroo (455 kg yr^{-1})

= (0.0124 g m^{-2} d^{-1}) × (365 d) × (100462 m^2)

= 454691.012g

= 455 kg

Leaching

TN output load from leaching at Bannister Creek (247 kg yr^{-1}) and Wanneroo (56 kg yr^{-1}) is derived from the multiplying between the rate of leaching process (0.00153 g m^{-2} d^{-1}) and area of soft surface (lawn and garden) at Bannister Creek (441952 m^2) and at Wanneroo (100462 m^2) as shown below.

TN output load from leaching at Bannister Creek (247 kg yr^{-1})

= (0.00153 g m^{-2} d^{-1}) × (365 d) × (441952 m^2)

= 246808.0944g

= 247 kg

TN output load from leaching at Wanneroo (56 kg yr^{-1})

= (0.00153 g m^{-2} d^{-1}) × (365 d) × (100462 m^2)

= 56103.0039g

= 56 kg

5.2.2 Phosphorus

Although the mechanisms that might contribute to P retention in the catchment were not measured, they were modelled using the rate of nitrogen processes provided by Dr Christian Zammit (Department of Environment) for Bannister Creek. The rates for P processes were plant uptake (0.0651 g m^{-2} d^{-1}), surface entrainment (0.000182 g m^{-2} d^{-1}), and vertical entrainment or leaching (0.00837 g m^{-2} d^{-1}).

The values for nitrogen processes provided by Dr Christian Zammit and Professor William Stock are used in quantify of N and P in each pathway of mass balance of nutrients. These values were determine through the LArge Scale CAtchment Model (LASCAM) developed with the aim of predicting the impact of land use and

climatic changes on the daily trends of streamflow and water quality (salinity, sediments, nutrients, etc.) in large catchments over long time periods. The key elements of LASCAM are published in, Viney and Sivapalan (1999) and Viney et al. (2000).

The model predicts catchment export of diffuse-source soluble and particulate phosphorus, particulate nitrogen, nitrate-nitrogen and ammonium-nitrogen. It explicitly includes the nutrient cycling processes of sorption, mineralisation, leaching, fixation, volatilisation, nitrification, denitrification, plant uptake and harvest losses. Soluble nutrients are assumed to be mobilised by surface runoff and by baseflow discharge, while particulate nutrients are associated with surface erosion and the stream sediment transport processes of deposition, re-entrainment, bed degradation and settling. The nutrient model includes 29 optimisable parameters, 11 for phosphorus and 18 for nitrogen, although several of these can be prescribed from measurements or from the literature. The model is applied to two large subcatchments of the 120,000 km^2 Avon River basin in Western Australia and shown to provide good predictions of daily nutrient export in a long-term simulation.

Table 7.12 Processes, load and percentage of phosphorus at Bannister Creek (BC) and Wanneroo (WN)

Mass Balance	Quantity of Phosphorus (kg yr^{-1})		Percentage (%)	
	BC	WN	BC	WN
Total TP Input Load	877	308		
Human Activities (Quest)	877	308		
Total TP Input Load	11909 (2388)	2702 (538)		
Prob Load	11909 (2388)	2702 (538)		
Total TP Storage	29	7	0.25 (1.23)	0.25 (1.24)
Surface Entrainment	29	7	0.25 (1.23)	0.25 (1.24)
Total TP Output Load	1180 (2359)	2696 (531)	99.76 (98.79)	99.75 (98.76)
TP output load from the drain	29	2	0.24 (1.20)	0.06 (0.28)
Plant uptake	10501 (980)	2387 (223)	88.18 (41.04)	88.34 (41.41)
Leaching	1350	307	11.34 (56.54)	11.36 (57.07)

5.2.2.1 Total TP Input Load (Table 7.12)

Total TP Input Load from human activities (Quest) at Bannister Creek (877 kg yr^{-1}) and Wanneroo (308 kg yr^{-1}) is derived from input load estimation of the questionnaires survey as shown in Table 4.10 and 4.11 respectively.

Total TP Input Load (Probability Load) at Bannister Creek (11909 kg yr^{-1}) and Wanneroo (2702 kg yr^{-1}) is derived from summation of the total TP storage and the total TP output load as shown below.

Total TP Input Load (Probability Load) at Bannister Creek (11909 kg yr^{-1})

= (29 kg yr^{-1}) + (11880 kg yr^{-1})

= 11909 kg yr^{-1}

Total TP Input Load (Probability Load) at Wanneroo (2702 kg yr^{-1})

$= (7\ kg\ yr^{-1}) + (2696\ kg\ yr^{-1})$

$= 2702\ kg\ yr^{-1}$

5.2.2.2 Total TP Storage (Table 7.12)

Total TP Storage at Bannister Creek (29 kg yr^{-1}) and Wanneroo (7 kg yr^{-1}) is derived from surface entrainment process as shown below.

Surface Entrainment

Total TP storage load from surface entrainment at Bannister Creek (29 kg yr^{-1}) and Wanneroo (7 kg yr^{-1}) is derived from the multiplying between the rate of surface entrainment process (0.000182 g m^{-2} d^{-1}) and area of soft surface (lawn and garden) at Bannister Creek (441952 m^2) and at Wanneroo (100462 m^2) as shown below.

Total TP storage load from surface entrainment at Bannister Creek (29 kg yr^{-1})

$= (0.000182\ g\ m^{-2}\ d^{-1}) \times (365\ d) \times (441952\ m^2)$

$= 29358.87\ g$

$= 29\ kg$

Total TP storage load from surface entrainment at Wanneroo (7 kg yr^{-1})

$= (0.000182\ g\ m^{-2}\ d^{-1}) \times (365\ d) \times (100462\ m^2)$

$= 6673.69\ g$

$= 7\ kg$

5.2.2.3 Total TP Output Load (Table 7.12)

Total TP output load at Bannister Creek (11880 kg yr^{-1}) and Wanneroo (2696 kg yr^{-1}) is derived from summation of TP output load from the drain, plant uptake, and leaching processes as shown below.

Total TP output load at Bannister Creek (11880 kg yr^{-1})

= (29 kg yr^{-1}) + (10501 kg yr^{-1}) + (1350 kg yr^{-1})

= 11880 kg yr^{-1}

Total TP output load at Wanneroo (2696 kg yr^{-1})

= (2 kg yr^{-1}) + (2387 kg yr^{-1}) + (307 kg yr^{-1})

= 2696 kg yr^{-1}

TP output load from the drain at Bannister Creek (29 kg yr^{-1}) and Wanneroo (2 kg yr^{-1}) is derived from annual nutrient output load estimation as shown in Table 5.10.

Plant uptake

Dr. Christian Zammit's information

TP output load from plant uptake at Bannister Creek (10501 kg yr^{-1}) and Wanneroo (2387 kg yr^{-1}) is derived from the multiplying between the rate of plant uptake process (0.0651 g m^{-2} d^{-1}) and area of soft surface (lawn and garden) at Bannister Creek (441952 m^2) and at Wanneroo (100462 m^2) as shown below.

TP output load from plant uptake at Bannister Creek (10501 kg yr^{-1})

= (0.0651 g m^{-2} d^{-1}) × (365 d) × (441952 m^2)

= 10501442.45 g

= 10501 kg

TP output load from plant uptake at Wanneroo (2387 kg yr^{-1})

= (0.0651 g m^{-2} d^{-1}) × (365 d) × (100462 m^2)

= 2387127.81 g

= 2387 kg

Professor William Stock's information

TP output load from plant uptake at Bannister Creek (980 kg yr^{-1}) and Wanneroo (223 kg yr^{-1}) is derived from information based on Professor William Stock as shown in below.

"Lawn is determined approximately 300-400 g m^{-2} (as dry weight), N varies from 1-4% of N let say approximately 2% of N in average and P varies from 0.1-0.4% P let say approximately 0.2 % P. Whereas shrubby is determined approximately 3.5 kg m^{-2} (as dry weight), N is assumed to be equal to 1.5% and P is assumed to be equal to 0.15%."

Based on assumption mentioned above

TP output load from plant uptake at Bannister Creek (980 kg yr^{-1})

Soft area in Bannister Creek is equal to 441952 m^2. This soft area is assumed to be divided into lawn area approximately 294635 m^2 (2/3) and garden area approximately 147317 m^2 (1/3).

Base on "Lawn is determined approximately 300-400 g m^{-2} yr^{-1} (as dry weight),and shrubby is determined approximately 3.5 kg m^{-2} yr^{-1} (as dry weight)"

Lawn = (294635m^2 × 300 g m^{-2} yr^{-1}) and (294635m^2 × 400 g m^{-2} yr^{-1})

= 88390400 g $catchment^{-1}$ yr^{-1} and 117853866.7 g $catchment^{-1}$ yr^{-1}

P varies from 0.1-0.4% of N let say approximately 0.2% of N in average

P composition in lawn = ($88390400 \times 0.2/100$ g catchment^{-1} yr^{-1}) and

= ($117853866.7 \times 0.2/100$ g catchment^{-1} yr^{-1})

= 176780.8 g catchment^{-1} yr^{-1} and 235707 g catchment^{-1} yr^{-1}

= 176 kg catchment^{-1} yr^{-1} and 235 kg catchment^{-1} yr^{-1}

= 206 kg catchment^{-1} yr^{-1} in average

Garden = (147317m^2 $\times$ 3.5 kg m^{-2} yr^{-1})

= 515611 kg catchment^{-1} yr^{-1}

P is assumed to be equal to 0.15% for shrubby in the garden

P composition in garden = ($515611 \times 0.15/100$ kg catchment^{-1} yr^{-1}

= 773 kg catchment^{-1} yr^{-1}

Total Phosphorus from plant uptake in Lawn&Garden = 206 + 773 kg catchment^{-1} yr^{-1}

= 979 kg catchment^{-1} yr^{-1}

TP output load from plant uptake at Wanneroo (223 kg yr^{-1})

Soft area in Wanneroo is equal to 100462 m^2. This soft area is assumed to be divided into lawn area approximately 66975 m^2 (2/3) and garden area approximately 33487 m^2 (1/3).

Base on "Lawn is determined approximately 300-400 g m^{-2} yr^{-1} (as dry weight),and shrubby is determined approximately 3.5 kg m^{-2} yr^{-1} (as dry weight)"

Lawn = (66975m^2 $\times$ 300 g m^{-2} yr^{-1}) and (66975m^2 $\times$ 400 g m^{-2} yr^{-1})

= 20092400 g catchment^{-1} yr^{-1} and 26789866.67 g catchment^{-1} yr^{-1}

P varies from 0.1-0.4% of N let say approximately 0.2% of N in average

P composition in lawn = ($20092400 \times 0.2/100$ g catchment^{-1} yr^{-1}) and

= ($26789866.67 \times 0.2/100$ g catchment^{-1} yr^{-1})

= 40184.80 g catchment^{-1} yr^{-1} and 53579.73 g catchment^{-1} yr^{-1}

= 40 kg catchment^{-1} yr^{-1} and 53 kg catchment^{-1} yr^{-1}

= 47 kg catchment^{-1} yr^{-1} in average

Garden = (33487m^2 $\times$ 3.5 kg m^{-2} yr^{-1})

= 117204.50 kg catchment^{-1} yr^{-1}

P is assumed to be equal to 0.15% for shrubby in the garden

P composition in garden = ($117204.50 \times 0.15/100$ kg catchment^{-1} yr^{-1}

= 176 kg catchment^{-1} yr^{-1}

Total Phosphorus from plant uptake in Lawn&Garden = 47 + 176 kg catchment^{-1} yr^{-1}

= 223 kg catchment^{-1} yr^{-1}

Leaching

TP output load from leaching at Bannister Creek (1350 kg yr^{-1}) and Wanneroo (307 kg yr^{-1}) is derived from the multiplying between the rate of leaching process (0.00837 g m^{-2} d^{-1}) and area of soft surface (lawn and garden) at Bannister Creek (441952 m^2) and at Wanneroo (100462 m^2) as shown below.

TP output load from leaching at Bannister Creek (1350 kg yr^{-1})

= (0.00837 g m^{-2} d^{-1}) $\times$ (365 d) $\times$ (441952 m^2)

= 1350185.46g

= 1350 kg

TP output load from leaching at Wanneroo (56 kg yr^{-1})

= (0.00837 g m^{-2} d^{-1}) × (365 d) × (100462 m^2)

= 306916.43g

= 307 kg

APPENDIX 6 - CATCHMENT CHARACTERISTICS

Catchment characteristics

Catchment Characteristics	Location m^2 (%)	
	Bannister Creek	Wanneroo
Foothpath	12428 (1.24)	990 (0.50)
Driveways&Pathway	82663 (8.27)	19070 (9.66)
Lawn & Garden	441952 (44.20)	100462 (50.90)
Roof	330581 (33.06)	48945 (24.80)
Street	132325 (13.23)	27908 (14.14)
Soft Surface	441952 (44.20)	100462 (50.90)
Hard Surface	557998 (55.80)	96914 (49.10)
Area Size m^2	999950	197376
Number of Houses	799	203
Number of Houses Sampling by Questionnaires	167	67